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METHODS FOR ESTIMATING EFFECTIVENESS AND COST OF CIVIL DEFENSE --ETC(U)

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LEVEL II

FINAL REPORT

METHODS FOR ESTIMATING EFFECTIVENESS AND COST OF CIVIL DEFENSE PROGRAM ELEMENTS

Prepared for:

Defense Civil Preparedness Agency
Washington, D.C. 20301

Contract: DCPA01-77-C-0223
Work Unit: 4114H

February 1978

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FINAL REPORT LEVEL II (11)

METHODS FOR ESTIMATING EFFECTIVENESS AND COST OF CIVIL DEFENSE PROGRAM ELEMENTS

by

Walmer E. Strope and John F. Devaney

for

Defense Civil Preparedness Agency
Washington, D.C. 20301

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DCPA REVIEW NOTICE

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Two related methods of assessing the cost-effectiveness of civil defense program elements in reducing casualties are presented, one a hand calculation procedure and the other a computer routine adapted to the current DCPA casualty assessment program. The methods employ a defense scenario that accounts for changes in population vulner-ability brought about by emergency operations and human behavior. (over)

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20. (continued)

Demonstration results are provided. Recommendations are made for further development.

DETACHABLE SUMMARY

METHODS FOR ESTIMATING EFFECTIVENESS
AND COST OF CIVIL DEFENSE PROGRAM ELEMENTS
Contract No. DCPA01-77-C-0223 Work Unit 4114H

This report documents an initial effort to develop methods for estimating the individual and combined contributions of various civil defense operating system elements to total system effectiveness in reducing casualties, and for relating the results to the costs of program elements. The methodology is applied to example civil defense programs.

The objectives are: to identify the elements of civil defense operating systems that contribute to reduction of casualties; to attribute direct and indirect costs to these elements; and to develop a method for assessing their effectiveness. The measure of effectiveness is limited to casualty reduction.

A distinction is made between the civil defense operating system, which functions during the emergency to reduce casualties, and the civil defense preparedness system, which functions during peacetime to provide capabilities and readiness for emergency operations. It is the preparedness system that incurs costs and the operating system that reduces casualties. A procedure is developed for tracing costs to the operating system elements.

The effectiveness of operating system elements is calculated by estimating from available data the amount by which the elements alter the vulnerability of the population. The influence of human behavior is included explicitly in the calculations. The basic concept used is a "defense scenario" in which the changes in population vulnerability are traced from shelter preparation, shelter assignment, and crisis movement through the warning and sheltering process to the postattack lifesaving operations.

The attack environment is drawn from a model in use by the Defense Civil Preparedness Agency. A recent large-scale, ground-burst hypothetical attack available at DCPA has been used to demonstrate the casualty assessment method. Two calculational procedures are developed for casualty

assessment. The first is a hand calculation employing two attack environment matrices, one for the areas experiencing direct effects and one for areas experiencing only fallout. A "cookie-cutter" assessment is made at appropriate points in the defense scenario using the median lethal overpressure (MLOP) for direct effects and an effective protection factor (PF) for fallout radiation. The effective PF is derived from the rated PF by accounting for the time of shelter leaving and for the application of remedial measures after leaving shelter.

The second procedure is a computerized calculation using the same defense scenario used in the hand calculation but operating on the attack environment and population vulnerability in two-minute grid squares as in the current DCPA casualty assessment system. Comparison of results from the two procedures indicates that the hand method can be used for assessing the relative cost-effectiveness of various program elements and can approximate absolute casualty levels when normalized to a few parallel computer runs.

The demonstration results of applying the assessment method to typical civil defense options are:

Posture	Fatalities	Injuries	Uninjured Survivors
No CD	80%	7%	13%
Current CD	76%	8%	16%
Program A	69%	10%	21%
Program B (In-Place Option)	62%	11%	27%
Program B (Relocation Option)	19%	13%	68%

The range of population fatalities varies from 20 percent to 80 percent depending on the nature of the civil defense option, where the estimate of effectiveness incorporates not only the likely performance of the civil defense capabilities brought by budgeted programs but also the anticipated behavior of the public.

The principal limitations of the proposed method are the limited evidence available to form the basis for performance estimates, and the limited knowledge of human behavior under crisis and attack conditions.

It is recommended that the proposed cost and effectiveness methodologies be adopted for DCPA cost-effectiveness analyses and that further analytical work be undertaken to improve the basis for estimating performance, to permit the separation of the joint performance of countermeasure sets into performance estimates for individual measures, and to indicate where further research investigations are needed to allow cost-effectiveness calculations to be used with confidence in policy decisions.

ABSTRACT

Two related methods of assessing the cost-effectiveness of civil defense program elements in reducing casualties are presented, one a hand calculation procedure and the other a computer routine adapted to the current DCPA casualty assessment program. The methods employ a defense scenario that accounts for changes in population vulnerability brought about by emergency operations and human behavior. Demonstration results are provided. Recommendations are made for further development.

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I. INTRODUCTION

Purpose

Estimates of the cost and effectiveness of defense systems have played a major role in development and deployment decisions for several decades. In the field of civil defense, considerable research effort has been devoted to the study of assessing cost-effectiveness. For the most part, previous studies have been confined to assessing the effectiveness of various kinds of protective shelter under assumed attacks, although the corresponding costs have usually included many other system elements and indirect investments, such as training, research, and management. Only occasionally have analyses considered explicitly the performance of warning systems, shelter stocks, ventilation systems, and the like in terms of an overall measure of effectiveness, such as added survivors.

The purpose of this report is to document an initial effort to develop methods for estimating the individual and combined contributions of various CD system elements to total system effectiveness, and for relating the results to the costs of program elements

Scope

The work reported here was performed for the Defense Civil Preparedness Agency under Contract No. DCPA01-77-C-0223, which contained the following scope of work:

> A. General - The Contractor, in consultation and cooperation with the Government, shall furnish the necessary facilities, personnel, and such other services as may be required to develop techniques for estimating the individual and combined contributions, to the total civil defense system effectiveness, of the important elements of that system. The Defense Civil Preparedness Agency (DCPA) now has well-developed techniques for estimating casualties that would be suffered by populations in various geographical distributions relative to specified assumed nuclear weapon detonations, and in various levels of protection against weapons effects; accordingly, the primary thrust of this project shall be to assess the effectiveness of civil defense system components in contributing to the population's making timely use of the best protection available, and remaining in protected locations long enough to minimize casualties due to attack effects. The results of this project are intended to improve DCPA's ability to allocate available funds and effort to areas of greatest expected payoff.

It will be noted that the effectiveness of civil defense operating system elements is to be measured by the change in expected casualties: fatalities, injuries, and uninjured survivors. Other possible measures are outside the scope of this work.

It is also specified that the conditions of analysis will be based on the occurrence of a week of severe crisis prior to attack rather than a short warning or "attack out of the blue." An important focus of the work concerns system elements that can be improved during the one-week "surge" period. Within this context, both in-place and crisis relocation postures are explored.

Limitations

The principal limitation of this work stems from the fact that the period of research spanned a six-month term of work, the first half of which was encumbered by participation in concurrent study efforts on an urgent basis. That is, the research was conducted concurrently with a series of workshops on CD program alternatives and a Department of Defense short-term analysis relating to the program review and budget cycle. As a result, it has not been possible to evaluate all system and program elements. The basic methodology is believed to be sound and to represent an advance in the state of the art. Effectiveness calculations of selected important system elements have been based on readily available data and are to be regarded as demonstration results only. Moreover, contributions to total system effectiveness were evaluated for natural groups of system elements or "countermeasure sets." Partition of these sets into individual element effectiveness was accomplished in only a few cases. Finally, many functional aspects of program elements were addressed only in principle.

Overview

This introduction is the first of five sections of the report. Section II identifies the elements of the civil defense operating system and their functional relationships, the associated program elements, and budget correlations. In Section III, the methodology for assessment of element effectiveness is described and demonstration results are exhibited.

The rationale for quantifying the performance of the various system elements is discussed in Section IV. The discussion includes: the basis for the values chosen for demonstration purposes; the possibilities for incorporating more detailed performance estimates in machine calculations; and the means for including other system elements. Limitations imposed by available data are indicated to the extent identified at this stage of study. Section V summarizes the results of the work and contains recommendations for both interim use and further development.

There are two appendices to the report. Appendix A by John F. Devaney contains an analysis of the FY 1978 DCPA budget. Appendix B by Dr. Fred Miercort is a brief description of the computer routine used in our machine calculations.

II. CIVIL DEFENSE SYSTEM AND PROGRAM ELEMENTS

Estimates of system cost and effectiveness are input information for the process of developing policies and deciding on the nature and extent of future CD preparedness programs. These estimates are useful in comparing programs, program elements, and alternatives. This attention to program elements aids in assuring balance so that the most preparedness can be obtained for the investment.

Systems and Programs

Civil defense is considered to be performed by two major systems:

- o Preparedness system: the one that is functioning now to build the operating system.
- o Emergency operating system: the one that would begin to function during a nuclear defense emergency to perform all the activities that make up civil defense.

Each of these major or total systems contains many components and subsystems.

Costs of civil defense are measured by the activities of programs of the preparedness system, described and approved for action in budgets. On the other hand, the effectiveness of civil defense should be measured by the performance of the operating system in countering nuclear attack effects. Thus, a crucial issue for this analysis is: how to define the performance of the operating system during an emergency in terms of preemergency investments in the preparedness program--i.e., given the level of investment (costs), what will be the operating system's effectiveness? Alternatively, the issue is: how to specify the performance requirements of the operating system so as to define the nature and required costs of the preparedness program (budget) --i.e., for a specified effectiveness, what will be the preparedness program cost? In either case, a methodology is needed to relate costs of the preparedness program to effectiveness of elements of the operating system.

Operating System Functions and Controls

Because this study is limited to estimating effectiveness in terms of change in casualties, the definition of the operating system is similarly limited:

> The operating system is a group of components functioning together under control to reduce casualties. The components include people, facilities, equipment, and supplies related by organization.

The operating system functions are those activities that counter the attack

effects to achieve the objective of reducing casualties. The controls are those activities that maintain the organizational relationships among components and keep them functioning together.

The nature of the functions and their required performance -- i.e., functional requirements -- are derived from analyses of attack effects and damage.[1] Control requirements are derived from the functional requirements. For convenience, all of the activities will be referred to as "countermeasures" except where there is benefit in identifying differences between functions and controls.

The Emergency Environment

The emergency environment -- i.e., the hazards, effects, and damage posed by an impending or actual attack -- is dynamic; it changes with time and from place to place throughout the emergency. As the environment changes, the requirements for operating system functions also change. The directions that the changes in emergency environment may take are shown in Figure 1.[1]

During the crisis period (Preattack--Crisis in Figure 1) when there is increased perception of the threat of attack, there are two basic options for reducing potential casualties from direct effects: to relocate (move) people from higher risk areas to lower risk areas: or to improve shelter in risk areas so that the people can be protected in place.

During the attack warning phase (Preattack--Attack Impending), moving the population to shelter reduces potential casualties from direct effects and fallout in risk areas and from fallout in lower risk areas.

After detonation of a nuclear weapon, the main continuing threats to life are weapon-caused fires and fallout radiation. Thus, during the attack phase (Transattack), the emergency environment may be described by three contingency situations (Hifire, Lofire, and Negfire) as shown in Figure 1. In each of these situations, fallout radiation may also be present in varying degrees.

The Transattack Hifire situation is the case where uncontrolled attack-caused fires force evacuation of the shelter base. The only option for the sheltered population is to relocate (remedial moving). If fallout is present, shelter is necessary at the new location in order to avoid fallout radiation casualties.

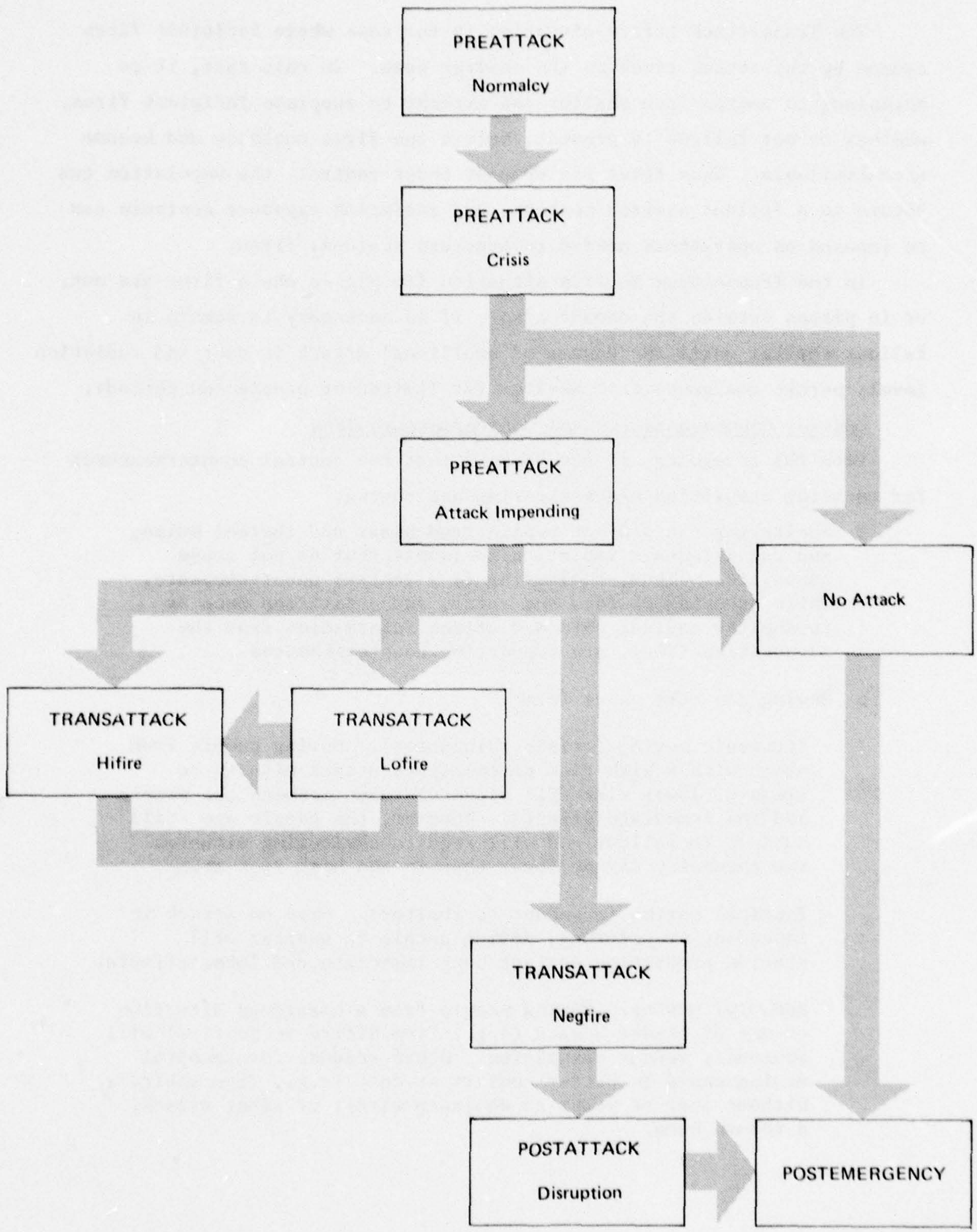

Figure 1 DYNAMICS OF ENVIRONMENT

The Transattack Lofire situation is the case where incipient fires caused by the attack threaten the shelter base. In this case, it is necessary to emerge from shelter and attempt to suppress incipient fires, whether or not fallout is present, before the fires coalesce and become uncontrollable. When fires are brought under control, the population can return to a fallout shelter posture, and radiation exposure controls can be imposed on operations needed to suppress residual fires.

In the Transattack Negfire situation (in places where fires are out, or in places outside the damage area), it is necessary to remain in fallout shelter until the danger of additional attack is over and radiation levels permit emergence from shelter for limited or protracted periods.

Central Countermeasures and Countermeasure Sets

From the foregoing, it can be seen that the central countermeasures for reducing casualties are sheltering and moving.

- Sheltering can protect people from blast and thermal pulse, and can attenuate radiation to levels that do not cause casualties. Thus, sheltering is a central countermeasure, while stocking of food and water, and activities such as in-shelter medical care and attack information from the authorities (EOC), are supporting countermeasures.

- Moving can take three forms:

  - Strategic moving (crisis relocation). Moving people from areas with a high risk of immediate attack effects to areas of lower risk will place distance between the people and the immediate effects. However, the people are still subject to fallout and will require sheltering although the intensity may be lower than in the high risk areas.

  - Tactical moving (movement to shelter). When an attack is impending or underway, moving people to shelter will provide protection against both immediate and later effects.

  - Remedial moving. Moving people from a hazardous situation to one of lesser hazard (e.g., from Hifire to Negfire) will obviously reduce casualties. Other reasons for remedial moving could be better comfort or care (e.g., from shelters without food or water to shelters with); or after attack, a return home.

In addition to the central countermeasures, other operating system functions and controls are required. For example, tactical moving to shelter requires: warning (to initiate the moving); maintaining order (to assist in expediting the moving); planning (to determine tactical moving needs and problems); commanding (to start the warning and issue instructions for solving problems); and informing (to provide information and instructions to people needing them).

Each central countermeasure and its supporting functions and controls constitute a set of countermeasures:

- o The Central Countermeasure performs the function required to reduce casualties in the particular attack environment.
- o Primary Support Countermeasures are those that are essential to the performance of the central countermeasure. Inability to support the central countermeasure would seriously degrade its performance.
- o Secondary Support Countermeasures are those that support the primary support countermeasures. Inability to do so would seriously degrade the primary support countermeasures.

The various operating system functions and controls considered in this study are shown in Table 1. Examples of how these functions and controls may be grouped into countermeasure sets are shown in Figures 2 through 5.

Figure 2 shows the set of countermeasures that would operate in the Preattack (Crisis) environment if crisis relocation were the protection mode. The identification of three central countermeasures in this case means that three sets of countermeasures are operating simultaneously: (a) people are relocating (strategic moving); (b) shelters are being improved in the host areas (improving facilities -- a preparedness system function); and (c) the people who have moved to the host area are being cared for (housing). Figure 2 shows that some of the primary support is in the form of actions while some is in the form of information that causes action. Figure 2 also shows how situation information flows back from the active countermeasures in the set.

Table 1

OPERATING SYSTEM FUNCTIONS AND CONTROLS

Functions	Mission
1. Sheltering	To shield against weapon and attack effects and to provide a viable environment for shelter occupants.
2. Warning	To alert people and to inform them so that prudent persons will act to bring themselves into the system as intended.
3. Moving	To move people to where the system can protect or support them and back home when displacement is no longer needed.
4. Rescuing	To assist people to move from a hazardous place to one of lesser hazard.
5. Maintaining Health	To minimize the spread of disease
6. Fire Fighting	To minimize personal injury and property damage by reducing thermal flux, probability of ignition, and burning rate; and by suppressing fires.
7. Maintaining Law and Order	To protect people and property against illegal acts and to improve system effectiveness by maintaining order.
8. Protecting Livestock	To minimize damage to, and denial of the product of, livestock.
9. Protecting Industry	To minimize damage to, and denial of the product of, industry.
10. Providing Medical Care	To minimize death and disability from illness and injury and to care for those displaced because of the threat of the attack effects.
11. Feeding	To provide food and water for those displaced by attack or threat of attack, or for those to whom normal supply channels are closed.
12. Housing	To provide temporary lodging to people displaced in a strategic or remedial movement.
13. Restoring Facilities	To repair or replace utilities and facilities vital to the survival of the people and the functioning of the system.
14. Decontaminating	To minimize denial of access and radiation damage by removing contaminating radioactive materials.
15. Providing Welfare Services	To provide material aid and counsel for people displaced by attack or threat of attack.
Controls	
1. Organizing	To control the employment of available staff, facilities, equipment, and supplies so as to maximize system readiness to use its remaining capability in the real emergency environment.
2. Planning	To define the problems existing in the situation and to inform the executive concerning the courses of action available to him and the probable results and expected risks for each.
3. Informing	To acquire data, process them into the required form, store and retrieve them, and communicate them to the persons who need them.
4. Deciding	To judge the relative worth and desirability of alternative courses of action and to select the course to be taken.
5. Commanding	To require that a selected course of action be taken and to review the effects of taking it.

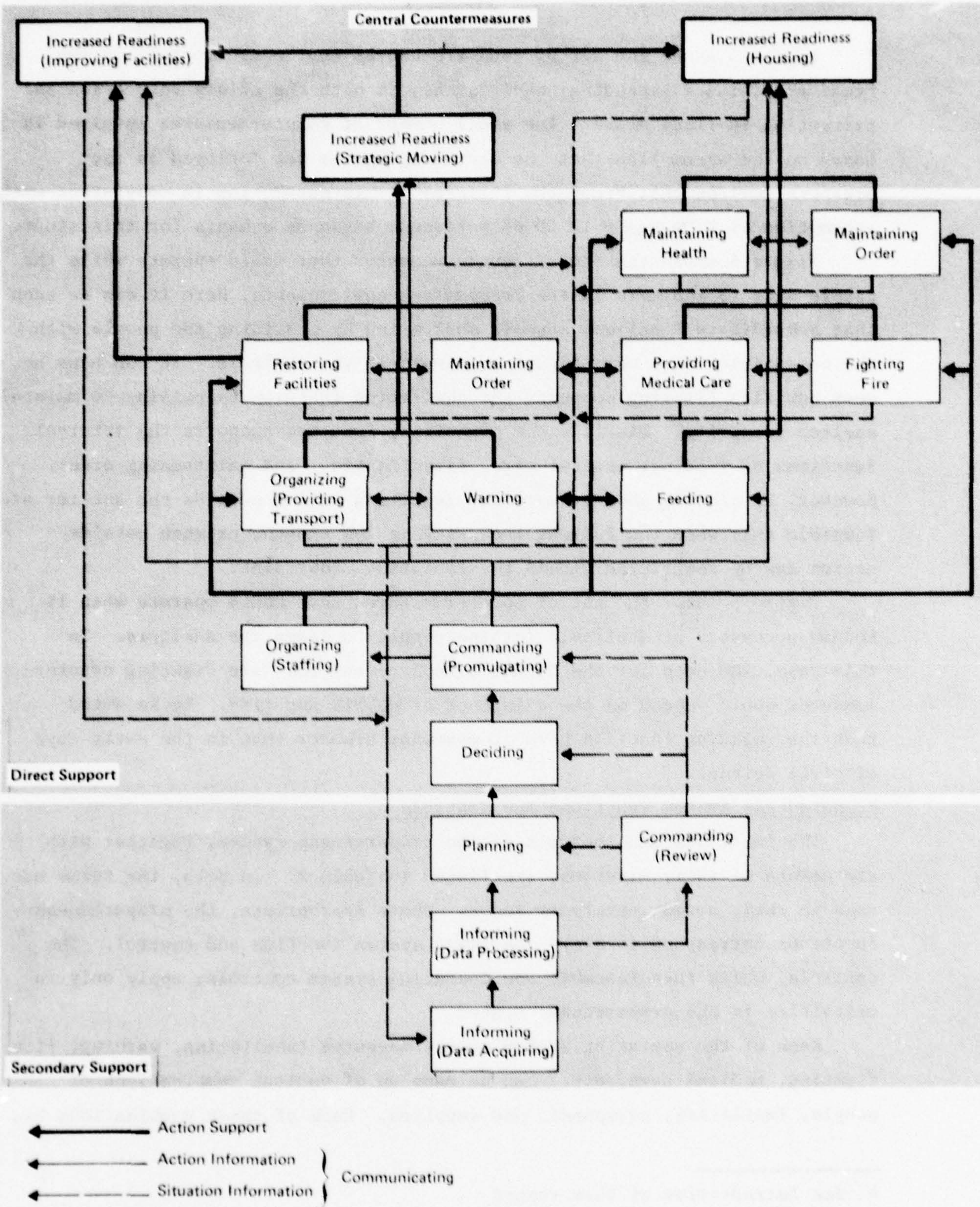

Figure 2 RELATIONSHIPS IN INCREASED READINESS COUNTERMEASURE SET
(Crisis Relocation; Environment: PREATTACK [Crisis])

Figure 3 shows the set of countermeasures that would operate in the Preattack (Attack Impending) environment, in both the crisis relocation and protection in-place modes. The small number of countermeasures involved is based on the assumption that the operating system was deployed in the previous environment: Preattack (Crisis). This assumption is consistent with the assumption of a "surge"* in CD preparedness taken as a basis for this study.

Figure 4 shows the set of countermeasures that would operate while the people were in shelters in the Transattack environments. Here it can be seen that subordinate functions support sheltering by providing the people with the necessities that permit them to remain in the shelters. It can also be seen how fire fighting supports the sheltering function by helping to maintain shelter integrity. Finally, the organizing function supports the internal functions of feeding, medical care, fire fighting, and maintaining order. However, as already shown, functions requiring action outside the shelter are feasible only when the fallout intensity is low enough, or when outside action can be restricted within the radiation constraint.

Figure 5 shows the set of countermeasures that would operate when it became necessary or desirable for the people to leave the shelters. In this case, the need for the Repair & Replace and the Fire Fighting countermeasures would depend on the existence of debris and fire. It is noted that the rescuing function here is somewhat broader than in the early days of civil defense.

Preparedness System Functions and Controls

The functions and controls of the preparedness system, together with statements of their missions, are listed in Table 2. In both, the terms are used in their normal, everyday sense. Where appropriate, the preparedness functions correspond to every operating system function and control. The controls, while they resemble the operating system controls, apply only to activities in the preparedness system.

Each of the operating system countermeasures (sheltering, warning, fire fighting, medical care, etc.) can be made up of various combinations of people, facilities, equipment, and supplies. Each of these combinations has

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* See Introduction of this report.

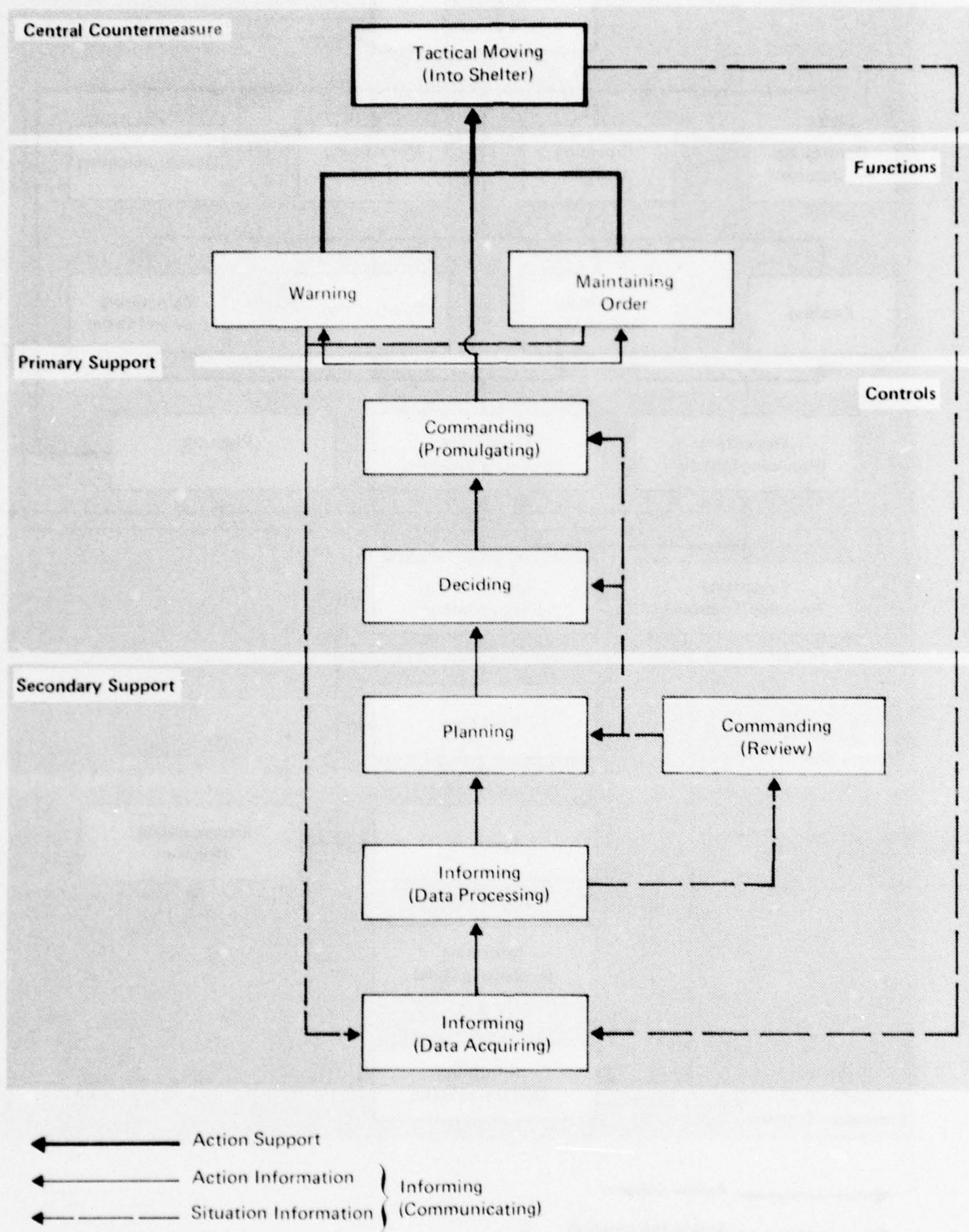

Figure 3 RELATIONSHIPS IN ENTER SHELTER COUNTERMEASURE SET (Crisis Relocation or Protection in Place; Environment: PREATTACK [Attack Impending])

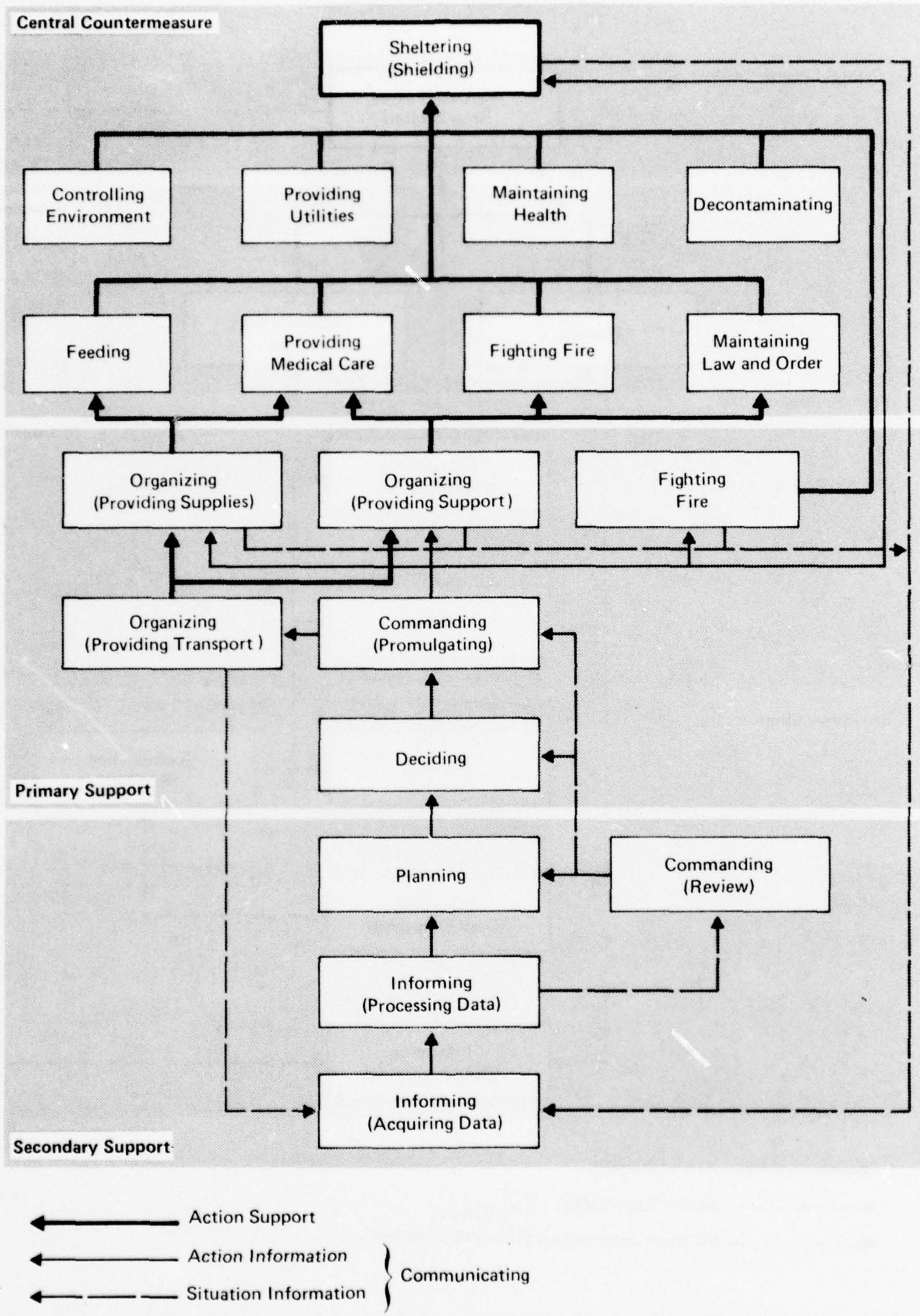

Figure 4 RELATIONSHIPS IN SHELTER COUNTERMEASURE SET
(Crisis Relocation or Protection in Place; Environment: TRANSATTACK
[Attack–Attack Ended])

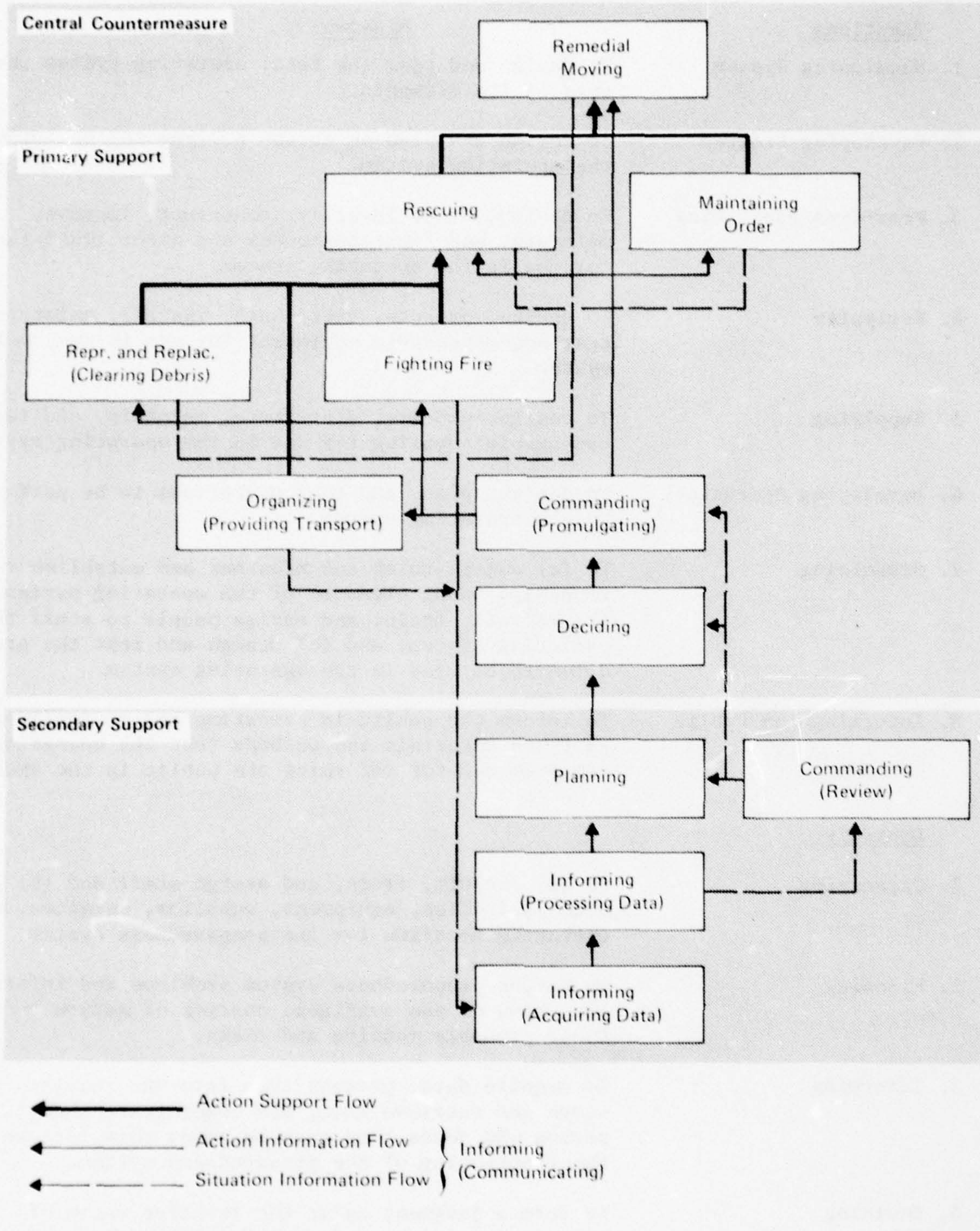

Figure 5 RELATIONSHIPS IN CHANGE PROTECTION COUNTERMEASURE SET (Crisis Relocation or Protection in Place; Environment: TRANSATTACK [Attack–Attack Ended])

Table 2

PREPAREDNESS SYSTEM FUNCTIONS AND CONTROLS

Functions	Mission
1. Developing System	To design and test the total operating system and sets of its elements.
2. Developing Program	To design and plan an action program for building the operating system.
3. Providing Facilities	To design, find, identify, construct, improve, maintain, and test structures and other fixed facilities for use in the operating system.
4. Equipping	To design, procure, distribute, install, maintain, and test non-expendable equipment for use in the operating system.
5. Supplying	To design, procure, distribute, maintain, and test consumable supplies for use in the operating system.
6. Developing Operations	To design, plan, and test operations to be performed by the operating system.
7. Organizing	To (a) assign roles and missions and establish relationships among elements of the operating system; (b) recruit, train, and assign people to staff the operating system; and (c) design and test the procedures to be used in the operating system.
8. Informing the Public	To inform the public in peacetime and to design and test the materials and methods that the operating system will use for informing the public in the emergency.
Controls	
1. Organizing	To (a) recruit, train, and assign staff and (b) provide facilities, equipment, supplies, services, and operating doctrine for the preparedness system.
2. Planning	To define preparedness system problems and inform the executive of the available courses of action and their probable results and risks.
3. Informing	To acquire data, process them into the required form, store and retrieve them, and communicate them to the person who needs them when he needs them for use in the functioning of the preparedness system.
4. Deciding	To form a judgment as to the relative worth of alternative courses of action and to select the one to be taken by the preparedness system.
5. Commanding	To require that a selected course of action be taken by the preparedness system and to review its effects.

an expected effectiveness in an assumed attack scenario and a given defense scenario. Each has a predictable cost. In theory, a desired level of system performance can produce functional requirements that can be the basis of an ideal design for the operating system. But the preparedness system functions are also subject to feasibility considerations, and it has been the case in U.S. civil defense that peacetime considerations of feasibility and cost have limited the performance of the preparedness system.

DCPA Budget Categories

Table 3 shows the outline of the DCPA "Justification of Estimates for FY 1978." The outline has two major headings: I. Operations and Maintenance; and II. Research, Shelter Survey and Marking. Under the first major heading are four principal divisions, for which the cost descriptions are as follows:

A. Warning and Detection. These are the major costs for the electronic systems: warning, communications, and radiological defense. Most of the costs are for maintenance and testing of facilities and equipment in elements of the operating system, but some are for the preparedness system itself.

B. Emergency Operations. Most of these costs are for training and education and for informing the public but also include some costs for communications (e.g., broadcast system protection). Practically all of the costs are incurred directly for the operating system.

C. Financial Assistance to States. These are contributions to States to supplement the funds they expend for civil defense. Roughly 40 percent of the costs are incurred directly for the operating system and 60 percent for the preparedness system. Again, some of these costs are for electronic systems: warning and communications.

D. Management. This includes all of the DCPA costs for personnel, travel, and administration and housekeeping. Some of the costs are incurred for the operating system directly, and some for the preparedness system.

Under the second major heading (Research, Shelter Survey and Marking) are three principal divisions, with cost descriptions as follows:

A. Shelters. About half of these costs are for shelter survey and marking, and half are for crisis relocation planning, most of which is addressed to planning for the relocation of people.

Table 3

FRAMEWORK OF THE DCPA BUDGET

(From Justification of Estimates - FY 1978)

I. OPERATIONS AND MAINTENANCE

A. WARNING AND DETECTION

Warning and Communication Systems

1.	National	a. National Warning System
		b. Washington Warning System
		c. CD National Teletype System
		d. CD National Voice System
		e. CD National Radio System
		f. Other Communications Services
		g. Technical and Administrative Support
2.	State and Local	a. Warning and Communications Planning Support

Radiological Defense

1.	National	a. Logistical Support
		b. Equipment Engineering
2.	State and Local	a. Maintenance and Calibration of RADEF Equipment
		b. RADEF Equipment

B. EMERGENCY OPERATIONS

Training and Education

1.	State and Local	a. Seminars
		b. RADEF Training
		c. Student Expense
		d. Training Materials

Emergency Information

1.	National	a. Information on the CD Programs
2.	State and Local	a. Liaison Services
		b. Architect and Engineers Technical Information
3.	Citizen	a. Information on CD Programs

Table 3 (continued)

Systems Development

1.	National	a. Relocation Planning b. Radiological Defense Planning

Broadcast Station Protection Program

1.	National	a. Seventeen remote pickup units... b. Additional emergency power... c. Fallout shelter repairs... d. Replacement of...equipment... e. Fallout and emergency power protection... f. Electromagnetic pulse protection...

Red Cross Advisory Services

C. FINANCIAL ASSISTANCE TO STATES

State and Local Management

State and Local Maintenance and Services

1.	State and Local	a. Direction and Control b. Alerting and Warning c. Emergency Public Information

D. MANAGEMENT

1.	National	a. Personal Services and Benefits b. Travel c. Administrative and Housekeeping

II. RESEARCH, SHELTER SURVEY AND MARKING

A. SHELTERS

Shelter Survey

1.	State and Local	a. National Shelter Survey b. Engineering Support Services

Nuclear Civil Protection Planning

Shelter Marking

Table 3 (concluded)

Shelter Stocking

Regional Emergency Operating Centers

Decision Information Distribution System

B. EMERGENCY OPERATING CENTERS

State and Local Emergency Operating Centers

1. State

2. Local

State and Local Supporting Materials

1. State and Local	a. Direction and Control System b. Emergency Services System c. Warning System

C. RESEARCH AND DEVELOPMENT

Nuclear Civil Protection Planning

Physical Protection

Emergency Operations

System Analysis

Training and Education

B. Emergency Operating Centers. These costs are for the warning system and communications equipment, as they relate to both State and local emergency operating centers.

C. Research and Development. These costs are all for the purpose of producing information to be used in preparedness system functions. However, most of these costs can be traced to operating system elements.

A demonstration analysis of the DCPA FY 1978 budget from the point of view of operating and preparedness systems costs is described in Appendix A and summarized in Figure 6. This analysis was termed a "demonstration" because there was not sufficient time or effort available in the study to make the records search that would have been required to thoroughly identify the operating system countermeasures and preparedness system functions and controls.

Cost Estimating Process

Two kinds of cost are of interest to the estimator:

- Direct Costs. The amounts that are expended for identifiable items in the completed work.

- Indirect Costs. The amounts that are expended to achieve the completed work but which cannot be traced to specific identifiable items.

The cost estimating process consists of five steps:

1. Analysis. The work to be done is divided into its major parts, usually on the basis of the nature of the items involved, and each part is analyzed. The different items having direct costs are identified, and their quantities are estimated.

   A chart such as Figure 6 is helpful in analysis. The operating system countermeasures (Sheltering, Warning, etc.) represent the completed work.* Then, moving down the column for each countermeasure, the estimator notes each preparedness system function (1. System Design, 2. Program Planning, etc.) and asks the question: "Is any of this preparedness system function involved in this work?" This procedure helps to assure that all items of direct cost are accounted for.

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* As shown in Appendix A, a coding procedure provides short-hand notation (O. for Operating System, F. for Functions, C. for Controls, etc.), so that for example, RADEF would be denoted by O.C.3.1 in Figure 6: O.Operating System, C.Controls, 3.Information, and 1.RADEF.

System	Group	Item	C. Controls: 1. Organizing	2. Planning	3. Informing	4. Deciding 5. Commanding	Subtotal Indirect Costs	F. Functions: 1. System Design	2. Program Planning	3. Facilities	4. Equipment	5. Supplies	6. Operations Planning	7. Organizing	8. Informing the Public	Subtotal Direct Costs	Total
O. OPERATING SYSTEM	F. Functions	1. Sheltering	2,120	115	1,006	2,476	5,717	1,825	948	3,932					168	6,873	12,590
		2. Warning	2,235	123	1,174	2,634	6,186		1,009	6,303						7,312	13,498
		3. Moving	1,707	93	889	1,994	4,683	100	764				4,504	169		5,537	10,220
		4. Rescuing															
		5. Maint.Health															
		6. Fire Fighting															
		7. Maint.Law & Order															
		8. Protect.Livestock															
		9. Protect.Industry															
		10. Medical Care	18	1	9	21	49		8	50						58	107
		11. Feeding	18	1	9	21	49		8	50						58	107
		12. Housing	323	18	153	377	871		144	900						1,044	1,915
		13. Restor.Facilities															
		14. Decontaminating															
		15. Welfare Services															
		O.F. All Functions	555	30	289	649	1,523	845	248				194		513	1,802	3,325
	C. Controls	1. Organizing	108	6	56	126	296		48					300		348	644
		2. Planning															
		3. Inform: 1. RADEF	4,433	78	746	1,674	3,931	26	641		2,698	132		1,152		4,649	8,580
		3. Inform: 2. Commun.	2,684	147	1,397	3,136	7,364		1,200	4,524	1,929		555	496		8,704	16,068
		4-5. Decid.& Command.															
		O.C. All Controls	393	21	204	459	1,027	26	176					1,073		1,275	2,352
		O. Total System	3,604	199	1,876	4,210	9,889	3,930	1,611					1,925	1,210	11,676	21,565
P. PREPAREDNESS SYSTEM		Note: All estimates in $000.	15,216	832	7,220	17,776	41,744	6,752	6,805	15,759	4,627	132	5,253	5,115	4,893	49,336	91,080
DCPA BUDGET	Operat.& Maint.	Warning & Detection			7		7			6,912	2,698	132	555			10,297	10,304
		Emergency Operations					—	152			400		194	2,890	683	4,325	4,325
		Finan.Assist. to States	7,498	523	4,184	11,172	23,377		4,277	1,716				1,210	2,646	9,849	33,226
		Management	7,718	309	3,729	6,604	18,360		2,528					715	1,564	4,807	23,167
	Res'ch,Shelter	Shelters					—			5,054			4,504			9,558	9,558
		Emergency Operat.Centers					—			2,071	1,529					3,600	3,600
		Research & Development			(6,900)		—	6,600						300		6,900	6,900

Figure 6 COST ESTIMATE FOR DCPA 1978 BUDGET

2. Pricing. Unit prices are applied to the quantities found in the analysis and the direct cost of each part of the work is determined. These part costs can be entered in the appropriate boxes under each countermeasure. Example: for sheltering, the part costs are for System Design, Program Planning, Facilities, and Informing the Public.

3. Direct Cost. The direct cost for each countermeasure is found by totaling the part costs (horizontally) for that countermeasure. Example: for Sheltering, the horizontal total is 6,873. The direct cost for each preparedness system function is found by totaling the part costs for that function for all countermeasures (vertically). Example: for System Design, the vertical total is 6,752. The total direct cost is found by summing the totals both ways (middle of Figure 6: Sub Total, Direct Costs).

4. Indirect Costs. In this method, the indirect costs are those incurred for preparedness system controls. This definition requires analysis of such expenditures as those included under the titles "Management" and "Financial Assistance to States" in the DCPA Budget section (Figure 6); then the expenditures appropriate to preparedness system functions can be allocated to them. Common practice is to proportion indirect costs dollars to direct cost dollars on the premise that dollars are a reasonable measure of work or of its value. Indirect costs may be spread back to the operating system countermeasures either as one amount or as detailed costs, the choice depending on the use to which the estimate is to be put.

5. Budget. Given the direct and indirect costs for the preparedness system as in Figure 6, they can be spread to the budget categories in whatever form the budget is to be presented.

The main benefits to be obtained from using the above method and a chart such as Figure 6 are: (a) it is possible to trace every element of operating system cost to the appropriate budget element and vice versa; and (b) it provides a demonstrable basis for relating budget element costs to operating system effectiveness, and can also aid in drafting budget descriptions that more effectively present the case for the proposed expenditures.

Program Phasing

It is unlikely that any operating system with acceptable effectiveness could be built in one year. Therefore, it is necessary to plan programs to extend over a number of years and to set program goals for some time in the future. In turn, because budget authorizations are largely annual, program goals must be set annually: X shelter spaces added year by year, X additional

warning, X amount of the population covered by additional emergency plans, etc. Given annual budgets and phasing of program accomplishments, there must also be phasing of the cost estimate.

From the phasing point of view, there are two kinds of direct cost for the operating system:

- o Capital Investment Costs. These are "first-time" expenditures for facilities, equipment, supplies, planning, staffing, etc. which add capability to the system.
- o System Maintenance Costs. These are the recurrent costs required to keep the capability added by capital investments. System maintenance costs include: repair of facilities and equipment; replacement of obsolete facilities, equipment, and supplies; testing; retraining of staff and training of replacements; and the like.

Estimating the cost of each annual increment of a program then becomes a two-part operation: estimating the capital investment cost, and estimating the system maintenance cost. As each increment is added to the system, the cost of the system tends to increase, because there are more items to maintain and because previous increments are growing older.

In estimating future capital investment costs, past investments are treated as sunk -- i.e., it is not necessary to include them in the estimated cost of the system. The same exclusion applies to items provided by society for other purposes but usable in the CD system -- e.g., the original buildings in which shelter capability is found, or the existing capabilities of fire departments. At the same time, the capabilities bought by past investments or found in society are recognized when estimating how the effectiveness will be increased by future expenditures. In other words, it is acceptable to use the "no civil defense" condition as the base case for estimating effectiveness so long as the increase in effectiveness is attributed to the investment that buys it.

Operating System Relationships

Effectiveness is the relationship between system performance and system demand. It answers the question, "How well does the system do the job it was given to do?" Whenever objectives are based on cost, effectiveness must be measured in terms of the quantity of performance meeting the specifications set by the demand. In this study the demand specification is: A person not

killed or injured. Then, given a sum of money for civil defense, effectiveness is measured by the number of people who would not be killed or injured* if the money were spent and the nation were attacked.

Effectiveness of Sheltering

Shelter protection is usually taken to be sequential: first, against direct effects (if any), and then, against fallout. Calculating the effectiveness of sheltering is also sequential, with effectiveness measured by reduction of casualties.

Casualties from direct effects are calculated by applying two damage functions to the number of people in a shelter. The Median Lethal Overpressure (MLOP) function is the overpressure at which there is a 50 percent probability of shelterees being killed, and the Median Casualty Overpressure (MCOP) function is the overpressure at which there is a 50 percent probability of shelterees being casualties (killed or injured).† A set of MLOP and MCOP functions is developed for each type of strength of shelter, generally on the assumption that people are randomly distributed within the shelter.

The calculation of damage from fallout is somewhat different. First the free-field dose†† for the shelter location is reduced by a protection factor (PF) which is a measure of the shelter's attenuation of the radiation flux.[4] Then the reduced radiation dose is compared to radiation damage functions that indicate probability of fatality or casualty, and the appropriate probabilities are applied to the number of people in the shelter.

The dose used in the fallout damage calculation is the Equivalent Residual Dose (ERD) which takes account of biological recovery as follows. A person subject to a radiation field receives a dose whose magnitude depends on the radiation intensity and the duration of exposure. As time passes, although his total dose increases, his body is repairing some (up to 90 percent) of the damage caused by radiation; the remaining 10 percent is not repairable. The casualty-producing effect of his maximum residual (unrepaired) dose is considered to be equivalent to that of an acute (one-time) dose of the same magnitude.

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* Injuries are attack-caused trauma, burns, and radiation sickness requiring professional medical attention.

† The functions also account for the damage from other direct effects that accompany, or result from, the given overpressure.

†† Dose at 1 meter above a uniformly contaminated, smooth, infinite plane.

Effective Protection

Use of the rated PF of a shelter in calculating fallout damage is based on an implicit assumption that the occupants remain in it long enough for the maximum ERD to occur while they are still in it. In most cases, this assumption would require a much longer stay than the two weeks generally used in shelter planning. On the other hand, events might dictate leaving the shelter temporarily or permanently at a much earlier time. Thus, most people taking shelter would experience some sequence of different protection situations. Therefore, the concept of effective protection is a critical consideration in calculating casualties and estimating effectiveness of countermeasures.

To demonstrate the concept of effective protection, two cases are presented:

(1) A person is in a shelter subjected to a fallout flux that produces a free-field maximum ERD = 10,000 r. If the shelter has a PF of 100, and he remains in it, he receives a Max ERD of 10,000/100 = 100 r.

(2) Another person is in the same shelter but leaves and goes to another shelter in a less intense fallout field and with a different PF. Overall, because of the dose enroute and the dose of the new location, it happens that he also receives a Max ERD = 100 r.

Although these two people started in the same situation, they had different exposure histories thereafter, but the net effect on them was the same: each received a Max ERD of 100 r. In other words, the sequence of protection situations that the second person experienced gave the same effective protection that he would have had if he had remained in the original situation. Then it can be said that the sequence of protections for the second person gave an effective protection of 100 PF.

Scenarios for Shelter Effectiveness

It has been stated that the defense would have a scenario just as would the attack. This defense scenario would describe what the defense would do, and when, to counter the attack and its effects. The defense scenario is an essential consideration in estimating effectiveness of elements of the operating system or of the budget. Following is a brief discussion of the role of the scenario in estimating the effectiveness of sheltering.

Figure 7 shows the framework for a scenario of the use of shelter. It is cast as a flow diagram of decision and action in a simplified pattern, and identifies three kinds of action or events:

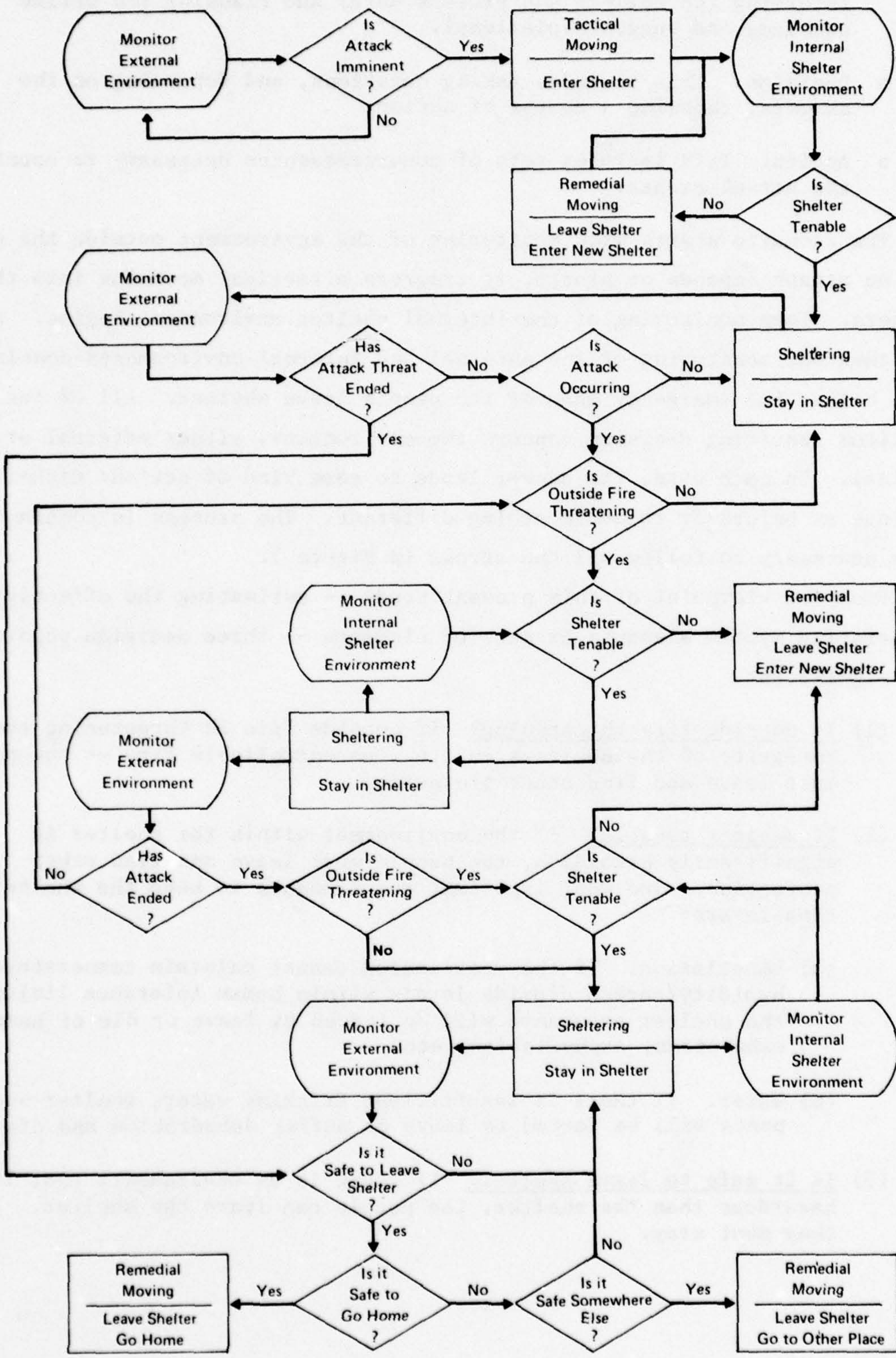

Figure 7 DECISION AND ACTION IN SHELTERING
(Protection in Place)

- o Monitoring. This includes the operating system activities of Informing (to collect and process data) and Planning (to define problems and suggest solutions).

- o Decision. This includes asking questions, and depending on the answers, choosing a course of action.

- o Action. This includes sets of countermeasures necessary to counter the attack events.

The scenario starts with monitoring of the environment outside the shelter. When an attack impends or starts, it triggers a tactical movement into the shelters. Then monitoring of the internal shelter environment begins. And from then on, monitoring of the external and internal environments continues until either the emergency ends or the people leave shelter. All of the questions requiring decision concern the environment, either external or internal. In each case, the answer leads to some kind of action: either to continue as before or to do something different. The process is continuous; it is necessary to follow all the arrows in Figure 7.

From the viewpoint of this present study -- estimating the effectiveness of operating system elements or sets of elements -- three decision points are most significant.

(1) Is outside fire threatening? If outside fire is threatening the integrity of the shelters -- i.e., uncontrollable fire -- the people must leave and find other protection.

(2) Is shelter tenable? If the environment within the shelter is significantly hazardous, the people must leave and find other protection. The most important requirements to keep the shelter tenable are:

(a) Ventilation. If the ventilation cannot maintain temperature/humidity/carbon dioxide levels within human tolerance limits, the shelter occupants will be forced to leave or die of heat exhaustion, asphyxiation, etc.

(b) Water. If there is insufficient drinking water, shelter occupants will be forced to leave or suffer dehydration and die of thirst.

(3) Is it safe to leave shelter? If there is an environment that is less hazardous than the shelter, the people can leave the shelter. If not, they must stay.

These three decision points are significant because each requires consideration of some combination of protection situations. As seen earlier, a combination of protections would yield an effective PF that would most likely differ from the rated PF of the shelter.

A number of protective actions -- by either the preparedness system or the operating system -- could serve to avoid premature departure from shelter and thus avoid a change of effective PF. For example, placing ventilation kits in the shelters would provide sufficient ventilation in many cases. Stocking the shelters with water would solve the water problem. Actions to inhibit fire starts or to improve fire fighting capabilities would help to reduce the external fire threat.

These two concepts of effective PF and defense scenario provide the basis for a method of estimating the effectiveness of countermeasures and countermeasure sets. The attack scenario establishes the attack-caused events that must be countered, and the defense scenarios establish the defense-caused events that (in many cases) must also be countered. Then, given these events, the CD measures to avoid or counteract their effects can be identified. In turn, the change in PF to an effective PF can be calculated, and the effective PF used in calculating the change in casualties.

This treatment of a scenario has been greatly simplified. For example, tactical moving and the several instances of remedial moving each would have its own scenario and each would influence the overall effectiveness. Other events can occur in the shelter, e.g., if an individual requires medical care that is not available in the shelter, remedial moving to a medical facility may be the solution for his problem. In addition, there are a number of support and supply actions that can be taken, in favorable circumstances, to alter the situation in the shelter.

The emphasis in this scenario discussion has been on fallout protection. However, there are scenarios that concern protection against immediate effects -- for example, tactical moving to shelter. Consideration could also be given to effective-PF equivalents against immediate effects. For example, if shelter occupants were to assume the best defensive posture, e.g., lying down away from the doors, this condition might change the MLOP and MCOP for

estimating direct effects casualties. Inducing shelter occupants to change their defensive posture would require effective shelter management. Thus, some version of this scenario could serve in estimating effectiveness of organizing shelter management, or of shelter manager training, or the like.

Effectiveness of Tactical Moving

Tactical movement to shelter is an important initial countermeasure that must be planned for. People cannot be expected to enter and stay in shelters unless there is believable indication of clear and present need.

It was seen earlier that the movement to shelter required several activities in addition to tactical moving: as a minimum, warning, maintenance of order, planning, informing, and commanding. The reason is that moving to shelter does not in itself reduce casualties. The shelters accomplish that, but the countermeasure set involved in moving to shelter affects the number of people in shelter, and effectiveness for them can be estimated indirectly. Two factors affect the number of people who are in necessary shelter: the number who go to their assigned shelters, and the time taken for them to get there.

Behavioral studies indicate that some small fraction of those who should go to assigned spaces in community shelters will not go. The number is probably affected by a number of factors: knowledge of the assignment or lack of knowledge; trust or mistrust of government officials; knowledge of whether the shelters are stocked and staffed for management, feeding, maintenance of order; and so on. Thus, some small fraction of the population will still be randomly distributed in their normal locations when the attack arrives.

For the great majority who do take shelter, their travel time can be divided into two periods: (1) the time from their awareness of impending or underway attack to the time when they begin moving to shelter, and (2) the time from beginning the move to the time of arriving in the shelter. The first period entails some short delay by the operating system in communicating the information to the local official who orders the warning, and another short delay until the warning starts. Then there is a delay while the people hear the alert, receive the information to move, receive confirmation, and

decide to go. All of these delays can be affected by the design of the warning system. Finally, there is a delay while making preparations to go. This delay can be affected by public information activities in the crisis, especially if there is a "surge" in CD preparedness actions.

The second period (moving and arrival) depends on distance to shelter and movement rate of the person. Distance depends on one's location when starting to shelter, and on the location of the shelter. Little can be done about the location of the people, but the locations of the shelters depend on their availability -- their numbers and distribution. Availability in turn depends on the design of the CD system. Movement rate and the rate of reaching shelter will be influenced by the assistance of the maintenance-of-order force in giving routing directions and in maintaining an orderly movement. This assistance becomes especially important when more people arrive at some shelters than capacity is available, while other shelters have space. In this case, the maintenance-of-order force -- assisted by the planners, communicators, and managers -- would direct the people to the available space. Such direction would increase the rate of reaching shelter.

The time taken for tactical moving to shelter has a significant effect on the distribution of people, especially those who are in the open while en route. In general, being in the open is the most hazardous situation. Therefore, the objective of the set of countermeasures involved in moving to shelter must be to minimize the time that people are in the open.

Given a weapon and a time of detonation, the effectiveness of the countermeasure set in tactical moving to shelter can be estimated -- individually and as a set. The estimates can be made directly by determining the distributions of the population and their protection during the move, relating the distributions to the MLOP and MCOP, and determining casualties on the basis of these relationships. Then changes in the countermeasures can be introduced, new distributions of the people calculated, and new estimates of casualties made. Comparison of these new estimates with the base case yields estimates of effectiveness of the various countermeasures used.

Effectiveness of Strategic Moving

In some respects, crisis relocation (strategic moving) is a substitute for sheltering against direct effects by moving the people from risk areas to where they are beyond the reach of hazardous direct effects. Crisis relocation

cannot be considered a substitute for fallout shelter because of the dimensions of the fallout areas. However, crisis relocation may place the people where the intensities of the fallout may be lower than those in their original risk-area location.

Estimating the effectiveness of crisis relocation against direct effects has some of the aspects of estimating the effectiveness of shelter. Thus, casualties are estimated for a base case (without moving) and for the relocated case (with moving). In each case, the casualties depend on the protection available where the people are assumed to be. Effectiveness is found in a comparison of the estimates of casualties between the base case and the relocated case.

Estimating the effectiveness of crisis relocation against fallout employs one distribution of PFs in the base case, and a different one in the relocated case. The time of fallout arrival will be later in the relocated case and the levels of fallout intensity will usually differ from those in the base case. The scenario for the relocated case will likely be different from that for the base case, especially with respect to fire hazard and the availability of drinking water in relocation sites. Casualties from fallout are calculated using scenario events to estimate effective PFs; these effective PFs give different maximum ERDs, and these ERDs cause different numbers of casualties.

Crisis relocation is subject to the same behavioral constraints that were noted for tactical moving. Some fraction of the population will decline to relocate, some will take longer to prepare for relocation, the movement rate can vary, and so on. The times required to relocate would likely be considerably longer than in the case of tactical moving, and people would be using autos and public transportation instead of walking. But the possibility of being attacked while moving would still have to be considered. Another difference from tactical moving would be the possibility of spontaneous movement of some fraction of the population in advance of the signal to go. Such movement would be more likely in the event of a preparedness "surge," especially if the people know that the government had plans for crisis relocation and had made preparations in the host areas.

Summary of Section II

In this section, it was seen that the emergency consists of a sequence of attack environments and that each of these required one or more different

sets of operating system countermeasures. It was also seen that the functioning of each countermeasure set followed a defense scenario that paralleled the attack scenario at least in its major aspects. There is also an overall defense scenario which includes all of the countermeasure set scenarios, some of which would likely be occurring at the same time in different places throughout the country.

The general utility of the scenario concept for the work reported here lies in its sequential nature. The scenario presents a sequence of actions and events, each action culminating in another event. At each event, the situation is different from what it was at the preceding event: attack effects, the numbers, conditions, and locations of the population and the available options -- all have changed.

These dynamics require that casualties be calculated sequentially, using the parameters discussed in this chapter (damage functions, population distributions, effective PF, maximum ERD, etc.) in each succeeding situation.

III. METHODOLOGY AND RESULTS

General Concept

The general concept of the methodology developed in this study is that in order to reduce casualties, operating system elements (and hence, the corresponding program elements) must reduce the vulnerability of some or all of the population. If an activity accomplishes no reduction in vulnerability, it cannot reduce casualties. If the activity does reduce vulnerability but the change cannot be quantified, the activity cannot be used in estimating the cost-effectiveness of countermeasures.

Casualty assessment procedures that relate population vulnerability only to the central countermeasures (sheltering or moving) will hide the contribution of the supporting operations to the reduction of casualties (e.g., warning, direction and control, RADEF, etc.).

The basic approach used here is to devise a "defense scenario" that traces the changes in population vulnerability and relates them to the attack environment, thus bringing hidden contributions to light. This scenario-type of casualty assessment methodology is intended to apply to any nuclear attack on the United States. In this report, we will exhibit casualty assessment results for a particular recently contrived attack, known as the 6A attack. The details of this attack are not pertinent to the objectives of this study other than to note that it is a very large, groundburst attack, that it is preceded by a week or two of intense international crisis, and that the timing of the attack is unspecified.

Relationship of Defense Scenario to DCPA Computer Program

The scope of work points out that DCPA possesses a well-developed casualty assessment system that should be used as the point of departure for this effort. Hence, the "defense scenario" approach has been adapted to the existing DCPA computer program, which will be described briefly.

The DCPA computer program operates on unit areas that consist of grid squares laid on the country, each square being two minutes of latitude and longitude (roughly two miles on a side). The attack environment portion of the program assesses the maximum blast overpressure and maximum ERD for fallout radiation in an unprotected location at the center of each grid square.

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We have accepted this output for this study although there are some problems inherent in the formulation, notably that the ERDs for particular grid squares are simply added without regard to variable fallout arrival times. This procedure overestimates the maximum ERD.

The calculation of fallout radiation dose follows the method of Schmidt.[5] The fallout model used is the WSEG-10 NAS-modified model.[6] The end-product of the model is the maximum ERD for a point of interest. The ERD calculation is sensitive to the effective time of arrival of fallout, but the current computer program does not keep a record of the arrival times lying behind the ERD computation. Hence, we have necessarily used arbitrary fallout arrival times in our modification of the casualty assessment routine. It would not be difficult to modify the attack environment portion of the existing program so that the most suitable arrival time could be recorded for use in the casualty assessment procedure.

The attack environment portion of the existing computer program results in assigning to each grid square a blast overpressure and a maximum ERD. Each grid square has a resident population. (The population distribution in current use represents the 1975 population of the United States totaling about 212 million.) Each grid square can also be identified as being located in a "risk area," "host area," or "neither." Grades of shelter or shelter-use rules can be linked to these identifiers. For crisis relocation actions, the population of all risk-area grid squares can be multiplied by a reduction factor, and the population of the host-area squares can be multiplied by an expansion factor to represent the relocation of people.

In the usual casualty assessment, the risk areas are defined by such criteria as census urbanized areas, places with population in excess of some value, or probabalistic attack assumptions. The remaining grid squares can be host areas except that some may be labeled "neither" on the basis of probable high fallout risk. In the example calculations of this section, the risk area is defined as all grid squares experiencing a blast overpressure of 2 psi or more in the 6A attack. The remaining grid squares constitute the nonrisk area. This is an abnormal procedure that has been adopted to simplify the presentation of the methodology and is not a limitation of the method.

The effect of the 6A attack environment on the population of the risk area is shown in Table 4. The population total shown in the heading presumes that 10 percent of the 156.1 million residing in the risk-area grid squares have evacuated spontaneously to the nonrisk areas during the crisis period. Since this emigration is assumed to be random in the risk areas, it does not change the population percentages given in the table. The entries in the body of the table indicate the portion of the population experiencing less than the stated ERD and overpressure. The zeros in the first column indicate that none of the risk area population is in grid squares experiencing less than 2 psi, which is in accord with the definition used in this example. Note that the bottom two lines contain identical percentages, indicating that none of the risk population experiences more than 50,000 ERD. (An example of using the table is as follows. Enter the table at 3,000 ERD and go across to the 15 psi column. Then 5 percent of the risk population experiences less than 15 psi and also less than 3,000 ERD.) The table has been limited to overpressures of 55 psi or less although the computer program output extends to 1,000 psi.

Table 5 shows the attack environment matrix for the nonrisk areas. Identical percentages in the columns for 2 and 4 psi indicate that none of the population in the nonrisk area experiences over 2 psi. The two lower lines show that, as in the risk areas, none of the population experiences over 50,000 ERD. For illustrative purposes these two tables will be used in a manual approximation of the proposed casualty assessment method.

Best Available Shelter

Current CD capabilities are based on sheltering the population in the best available shelter in existing buildings, tunnels, mines, and caves. Also, many candidate CD programs are based on the use of best available shelter augmented by upgraded, expedient, or constructed shelter of various kinds. Table 6 describes the all-effects shelter types used by DCPA. Table 7 indicates the rated protection factors assigned to these shelter types by DCPA. In the third column, the first number refers to the rated median lethal overpressure (MLOP) and the second number refers to the median casualty overpressure (MCOP). In the DCPA casualty assessment procedure, these values represent the midpoints of probability distributions that have been developed for each shelter category. The maximum

Table 4

ATTACK ENVIRONMENT MATRIX (ATTACK 6A) FOR RISK AREA

(Population 140,489,471 After 10% Decrease by Spontaneous Evacuation)

Percent of Population Experiencing Less Than Indicated ERD(r) and Blast Overpressure(psi)

ERD	2 psi	4	5	7	8	10	14	15	25	35	55 psi
200 r	0.0	0.0	0.0	0.0	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%
300	0.0	0.0	0.1%	0.1%	0.1	0.1	0.2	0.2	0.2	0.2	0.3
500	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4
750	0.0	0.1%	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.7
1000	0.0	0.2	0.3	0.4	0.5	0.6	0.8	0.8	1.0	1.2	1.4
1500	0.0	0.4	0.6	0.8	0,9	1.1	1.5	1.6	2.0	2.4	2.7
2000	0.0	0.6	0.9	1.2	1.4	1.8	2.3	2.6	3.4	3.9	4.5
3000	0.0	1.2	1.7	2.4	2.8	3.5	4.7	5.0	6.6	7.6	8.6
5000	0.0	2.3	3.2	4.7	5.4	6.9	9.7	10.4	14.3	16.3	18.2
7500	0.0	3.4	4.9	7.4	8.6	11.7	16.7	18.0	25.5	29.5	33.2
10000	0.0	4.2	5.9	9.6	11.5	15.3	22.7	24.6	35.8	41.5	46.8
20000	0.0	6.0	8.4	13.6	16.1	21.2	30.5	33.8	49.8	58.7	66.7
50000	0.0	6.5	9.1	14.7	17.4	23.0	34.0	36.7	54.6	65.2	75.2
100000 r	0.0	6.5%	9.1%	14.7%	17.4%	23.0%	34.0%	36.7%	54.6%	65.2%	75.2%

Table 5

ATTACK ENVIRONMENT MATRIX (ATTACK 6A) FOR NONRISK AREA

(Population 71,226,998 After 10% Increase by Spontaneous Evacuation)

Percent of Population Experiencing Less Than Indicated ERD(r) and Blast Overpressure(psi)

ERD	1 psi	2	4 psi
200 r	5.7%	5.8%	5.8%
300	6.9	7.0	7.0
500	10.2	10.3	10.3
750	14.3	14.5	14.5
1,000	18.2	18.5	18.5
1,500	25.3	26.0	26.0
2,000	31.9	33.0	33.0
3,000	42.4	44.2	44.2
5,000	57.7	60.9	60.9
7,500	69.0	73.7	73.7
10,000	75.3	81.0	81.0
20,000	88.1	96.5	96.5
50,000	90.9	100.0	100.0
100,000 r	90.9%	100.0%	100.0%

Table 6

RELATIVE BLAST PROTECTION CODES*

Preference	Description
A	Subway stations, tunnels, mines, and caves with large volume relative to entrances.
B	Basements and sub-basements of massive (monumental) masonry buildings.
C	Basements and sub-basements of large, fully engineered structures having any floor system over the basement other than wood, concrete flat plate, or bandbeam support.
D	Basements of wood frame and brick veneer structures including residences.
E	First three stories of buildings with "strong" walls, less than ten aboveground stories, and less than 50% apertures.
F	Fourth through ninth stories of buildings with "strong" walls, less than ten aboveground stories, and less than 50% apertures.
G	Basements and sub-basements of buildings with a flat plate or band beam supported floor system over the basement.
H	First three stories of buildings with "strong" walls, less than ten aboveground stories, and greater than 50% apertures, or first three stories of buildings with "weak" walls and less than ten aboveground stories.
I	All aboveground stories of buildings having ten or more stories. Fourth through ninth stories of buildings having "weak" walls.

NOTE: For the above description, load bearing walls are considered as "weak" walls.

* Taken from DCPA Attack Environment Manual, Chapter 2, as revised November 1974.

Table 7

DCPA SHELTER CATEGORIES

Category	Shelter Type	Rated MLOP/MCOP	Rated Protection Factor(PF)
1	A	35/25	5,000
2	B/C	10/7	500
3	D	10/4	25
4	E/F	8/2	55
5	G/H/I	5/2	70
6	Unwarned or No CD	4/2	10

blast overpressure computed for a grid square is compared with the appropriate casualty function to determine the fraction of the population that are fatalities or casualties.

To determine fallout radiation fatalities, the maximum ERD computed for a grid square is divided by the appropriate PF, and the result is compared with a casualty function in which the median lethal dose (MLD) is taken to be 450 roentgens. For radiation injury among those not injured by blast overpressure, the result is compared to a casualty function in which the median injury dose is 250 roentgens. For those already injured by blast, the median injury dose is reduced to 200 roentgens.

Also shown in Table 7 is a sixth category of protection related to the "Unwarned" or "No Civil Defense" situation. The overpressure protection assumes that the population is in normal locations, mostly indoors aboveground. The rated PF assumes that survivors of direct effects seek basement shelter where it is available.

Variations from Rated Protection

The actual protection afforded by shelters can vary from the ratings shown in Table 7. With respect to shelter type, there would be a wide variety of specific structures within the general (A,B,C, etc.) description, and PFs would vary accordingly. With respect to shelteree behavior, the rated MLOP/MCOP represent an average between the vulnerability of people in the standing position and vulnerability in the prone position. Otherwise, people are considered to be randomly distributed throughout the shelter area. The ratings themselves undoubtedly are judgmental in striking a broad average estimate of blast protection. In this study, the overpressure ratings of Table 7 were used without modification. Possible alternatives are discussed in Section IV.

The rated PFs for the shelter categories in Table 7 are also average values for classes of structures having a considerable range of radiation protection characteristics. Moreover, they are based on the calculated or engineering protection factors of such structures.

The rated PF also implies that people remain in the sheltered location indefinitely -- not necessarily forever but for at least several months. This extended period is generally not practical. The reason that the rated PF often does not represent the real protection offered by a shelter stay is illustrated in Figure 8.

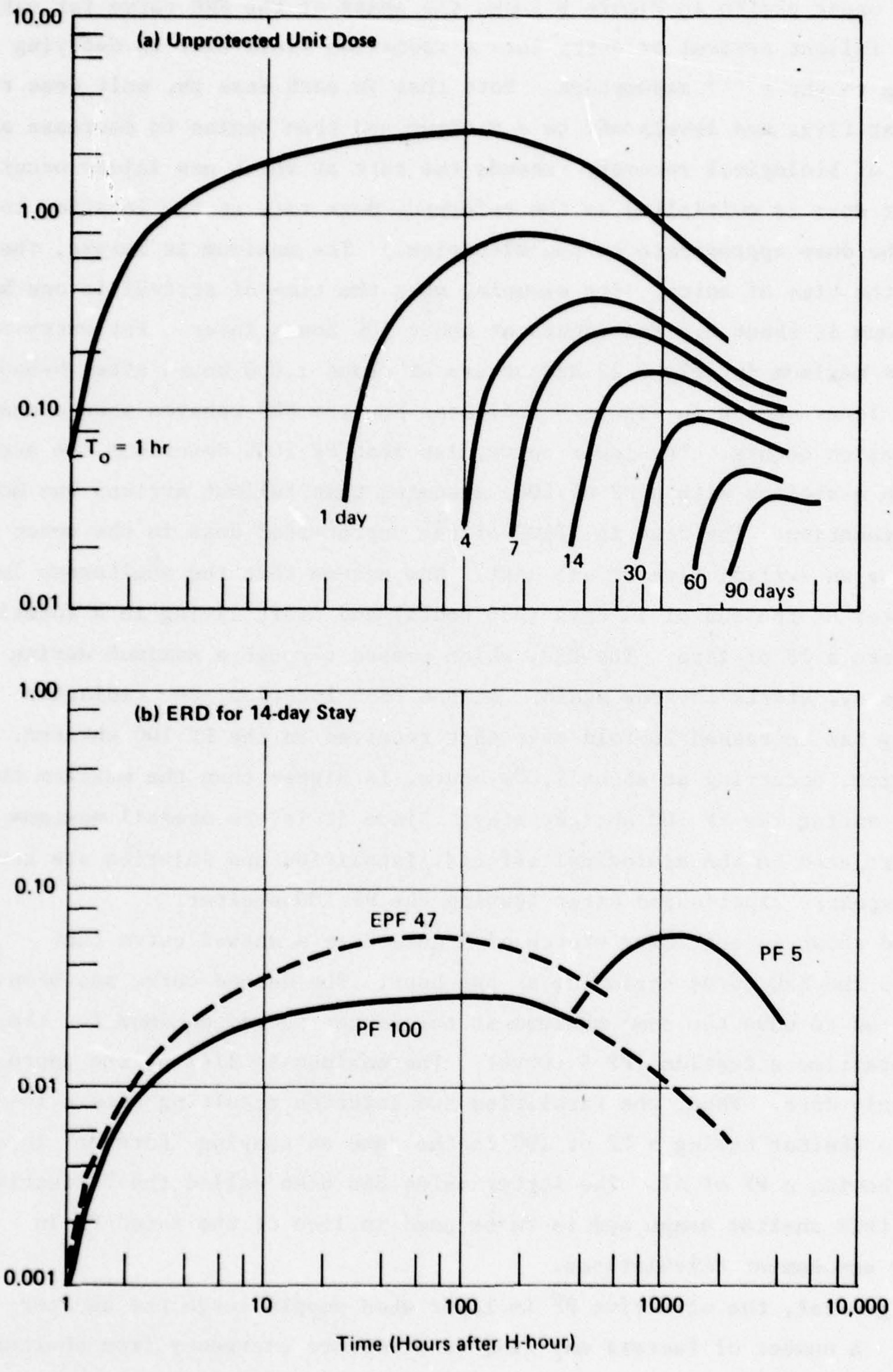

Figure 8 EQUIVALENT RESIDUAL DOSE

The upper sketch in Figure 8 shows the shape of the ERD curve for various times of fallout arrival or entry into a radiation field that is decaying according to the $t^{-1.2}$ assumption. Note that in each case the unit dose rises rapidly at first and levels off to a maximum and then begins to decrease as the rate of biological recovery exceeds the rate at which new injury occurs. (The unit dose is multiplied by the reference dose rate at the location to obtain the dose appropriate to the situation.) The maximum is larger, the earlier the time of entry. For example, when the time of arrival is one hour, the maximum is about 2.8 and occurs at about 100 hours later. For entry at 14 days, the maximum is only 0.22 and occurs at about 1,000 hours after H-hour.

The lower sketch in Figure 8 indicates how the ERD behaves when a change in protection occurs. The lower curve, labeled "PF 100" describes the accrual of ERD in a shelter with a PF of 100, assuming that fallout arrives one hour after detonation. The dose is 1/100 of the unprotected dose in the upper sketch for an arrival time of one hour. Now assume that the shelterees leave the shelter at the end of 14 days (336 hours) and start living in a location that offers a PF of five. The ERD, which passed through a maximum during the shelter stay, starts to grow again. At the PF 5 location, the radiation intensity has increased 20-fold over that received in the PF 100 shelter. A new maximum, occurring at about 1,000 hours, is higher than the maximum that occurred during the PF 100 shelter stay. Since it is the overall maximum dose that is related to the biological effects, fatalities and injuries are governed by the exposure experienced after leaving the PF 100 shelter.

Also shown in the lower sketch of Figure 8 is a dashed curve that parallels the ERD curve beginning at one hour. The dashed curve has been constructed to have the same maximum as the larger second maximum for the 14-day staytime situation (PF 5 curve). The maximum is 1/47 of the unprotected unit dose. Thus, the fatalities and injuries resulting from a 14-day stay in a shelter having a PF of 100 is the same as staying "forever" in a shelter having a PF of 47. The latter value has been called the "effective PF" for this shelter usage and is to be used in lieu of the rated PF in casualty assessment calculations.

In general, the effective PF is lower when people leave the shelter earlier. A number of factors may lead to premature emergency from shelter -- lack of adequate ventilation, lack of drinking water or other essentials,

lack of leadership, lack of communications, lack of radiation instruments, and the like. Only for shelters offering a low level of protection does the effect of premature emergence make little difference in the number of casualties. This can be seen in Figures 9 and 10. Figure 9 shows the effective PF for a range of rated PFs and emergence times for an effective fallout arrival time of one hour. This arrival time is assumed to be applicable to risk areas. Figure 10 shows the same information for an effective arrival time of five hours, which is assumed to be appropriate for the nonrisk area.

<u>The "No Civil Defense" Case</u>

A base case called "No Civil Defense" is often used to estimate the casualty reduction afforded by various CD programs. In the base case, the entire population is assumed to have the protection indicated in Category 6 of Table 7. In the machine computation, casualties are assessed for each grid square and summed to obtain area or national totals. An equivalent hand calculation can be made using the attack environment matrices of Tables 4 and 5. The hand calculation uses the "cookie-cutter" approximation of the casualty functions employed in the machine computation. For complex protection situations, the cookie-cutter approximation results in an error of perhaps 5 to 10 percent. For a simple case, such as the No Civil Defense case, it is sufficiently accurate.

We note from Table 7 that the MLOP for the No Civil Defense case is 4 psi. We assume that the MLOP is a step function -- everyone experiencing over 4 PSI is a fatality and everyone experiencing less than 4 psi is a survivor of direct effects. Entering Table 4 at the highest ERD value (less than 100,000 ERD), we find that 6.5 percent of the risk-area population experience less than 4 psi and are survivors of blast effects.

Some of the No Civil Defense survivors of blast effects may have insufficient fallout protection at the rated PF 10 (Table 7). According to Figure 9, the effective PF for a stay of at least one week is about the same as the rated PF. Taking the median lethal dose to be 450 ERD, the unprotected ERD would have to be less than 4,500 to avoid fatalities. In Table 4, 1.2 percent of the *surviving risk-area* population is found to be at less than 3,000 ERD, and 2.3 percent at less than 5,000 ERD. A linear interpolation indicates that about 2.0 percent would be at less than 4,500 ERD. Taking the Table 4 population figure

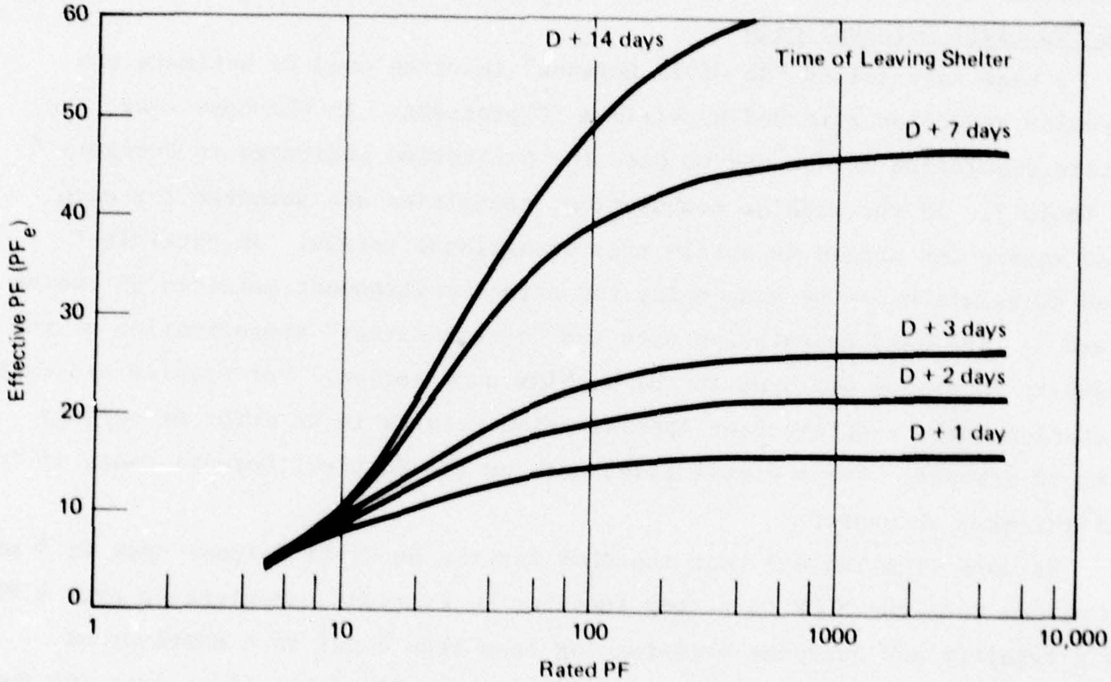

Figure 9 EFFECTIVE PF FOR NO REMEDIAL MOVING AND FALLOUT ARRIVAL TIME OF ONE HOUR

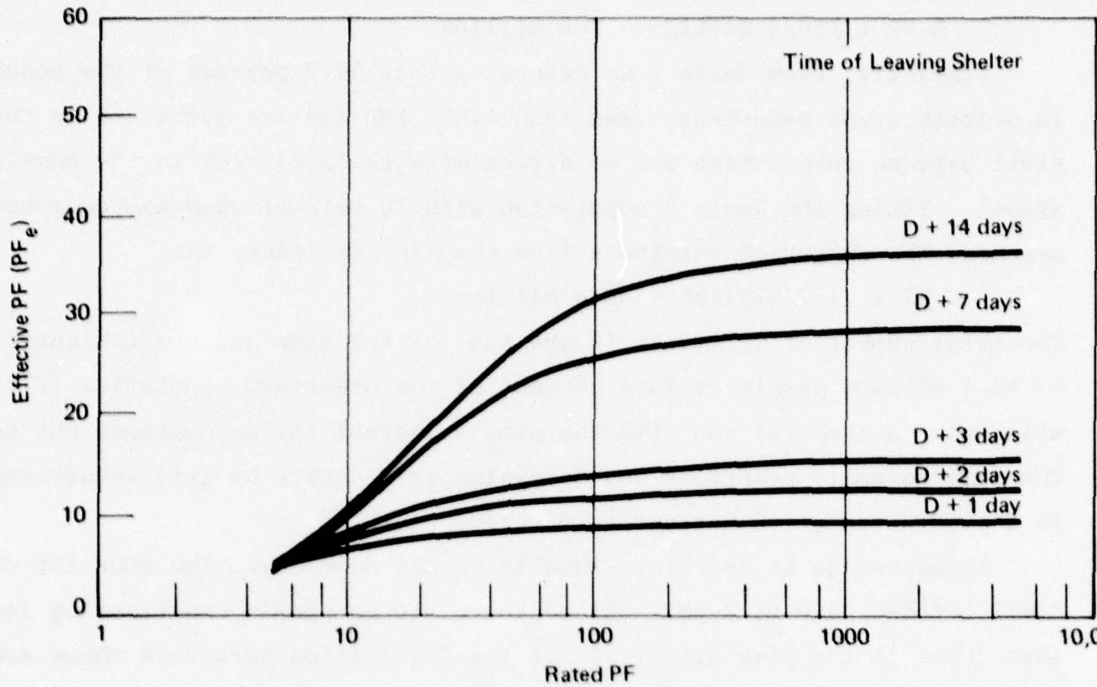

Figure 10 EFFECTIVE PF FOR NO REMEDIAL MOVING AND FALLOUT ARRIVAL TIME OF FIVE HOURS

of approximately 140.5 million (10 percent spontaneous evacuation assumed), we calculate the survivors in the risk areas to be:

0.02 x 140.5 million = 2.8 million

Similarly, from Table 5 we determine that 56.7 percent of the population in nonrisk areas experience less than 4,500 ERD and are survivors in the No Civil Defense case (there are no direct effects fatalities in the nonrisk areas). Taking the Table 5 population with 10 percent spontaneous evacuation assumed, the number of survivors from the nonrisk areas, is:

0.57 x 71.2 million = 40.6 million

The total number of survivors is the sum of the risk and nonrisk survivors -- 43.4 million people or 20.4 percent of the preattack population (212 million). A computer run with the same vulnerability assumptions but using the full casualty functions and assessing grid square by grid square results in a prediction of 20 percent survivors.

Injuries can be assessed manually in the same way. The MCOP for the No Civil Defense case is 2 psi. Since there are no people experiencing less than 2 psi in the risk areas, all of the 2.8 million survivors there are assessed as injured survivors. Using 200 ERD as the injury dose in this situation, it is seen in Table 4 that 0.6 percent of the surviving 2.0 percent experiences less than 2,000 ERD. The remainder, 70 percent of the survivors, are injured by radiation as well as blast.

Since all of the population of the nonrisk areas experiences less than 2 psi, there are no blast injuries. Using 250 ERD as the injury dose under this condition and multiplying by a PF of 10, we interpolate in Table 5 to find that 38.6 percent of the nonrisk population experience less than 2,500 ERD and are assessed as uninjured survivors. Thus, of the preattack population, 0.39 x 71.2 million = 27.5 million or 13 percent are uninjured survivors. Injured by radiation are the other 13.1 million. The total injured are 2.8 + 13.1 = 15.9 million or 7.5 percent of the preattack population. The machine calculation obtains 7 percent injured and 13 percent uninjured.

According to Figures 9 and 10, the foregoing calculation is valid only if the population remains in the assumed protection (PF 10) for at least one week. One may question whether this is a reasonable assumption, even should a week or two of crisis precede the attack. There would, for example, be a very limited source of radiation measurements, largely at military installations, to form a basis for guidance to the public. Since radiation cannot be

seen or felt, many people would see no reason to remain in shelter or indoors for an extended period. One way to evaluate the importance of this behavioral question would be to make a parallel calculation that assumes that people remain in shelter only for a day or so.

Figure 9 indicates that the effective PF for shelter emergence at one day is about 8 rather than the rated factor of 10. Consulting Table 4, it can be determined that under these circumstances only 1.5 percent of the risk area population survives rather than 2 percent. Figure 10 indicates that in nonrisk areas the effective PF would be about 6.5 rather than 10. Using Table 5, it can be determined that 43 percent of the nonrisk population survive rather than 57 percent as calculated previously. The new result would be:

0.015 x 140.5 million =	2.1	million
0.434 x 71.2 million =	30.9	million
Total Survivors	33.0	million

or 16 percent of the preattack population. Thus, the ability to cause the population, if only in heavy fallout areas, to remain in basements and houses for at least a week is worth over 10 million added survivors.

The likely No Civil Defense case lies between these two extremes. Since some CD preparations have existed during the nuclear era, there is no way to estimate the behavior of people in the absence of such preparations. One can say that in event of a sudden attack, survival would likely be near the lower estimate. In circumstances of a crisis, public information could play a key role. If only 10 percent of the population were influenced toward proper behavior, about a million additional people would survive.

Another behavioral question is implied by the assumption that 10 percent of the risk area population would evacuate spontaneously during the crisis period. If no spontaneous relocation occurred, there would be 156.1 million people in the risk areas and only 55.6 million in the nonrisk areas. A calculation similar to that above, assuming shelter stays of at least a week, would indicate that only about 35 million would survive, again about 16 percent of the population. And, if occupancy of available basements and houses lasted only a day, the survivors could number only 13 percent.

On the other hand, spontaneous evacuation could be much greater than assumed, as discussed in the next section of this report. If 30 percent left the risk areas, for example, and behaved with caution and discipline for a

week or two after attack, the calculation would indicate that 60.6 million would survive, about 29 percent of the preattack population. Thus, quite aside from any technical uncertainties, the survivors under this large weapons-rich attack in the No Civil Defense case could range from 13 percent to 29 percent of the preattack population depending on the behavior of people. In turn, the main tool for influencing behavior would be a crisis public information activity. Were such an effort competent and credible in motivating the population, it would have the potential to save up to 34 million lives. Of course, lacking other preparedness measures, nearly three-quarters of the population would still perish.

Marginal Cost-Effectiveness

The discussion above is typical of the uncertainties in casualty assessment. Many technical as well as behavioral aspects of the performance of the CD operating system are poorly known or unknowable. In these circumstances, it is often useful to calculate the marginal effectiveness of a measure -- that is, the expected return in casualty reduction if only a small increment of the population, say 1 percent, were moved from condition a to condition b.

Thus, it was estimated earlier that under certain conditions in the No Civil Defense case, the survivor rate in risk areas could be expected to be 2 percent, and the survivor rate in nonrisk areas, 57 percent. The difference between these two rates is 55 percent. Statistically, an individual moving from a risk area to a nonrisk area during a crisis changes his chance of survival by this amount. In other words, of every 100 people evacuating spontaneously in a crisis, 55 are added survivors. If emergency public information were to cause only 1 percent additional evacuees from the risk areas, one would estimate about 860,000 additional survivors. (The effect on injuries could also be calculated.)

Often, the comparison of the cost of a program element with its marginal effectiveness will provide strong justification on the basis of cost per added survivor. In this event, a more precise knowledge of the likely effectiveness may not be necessary. We will mention the marginal effectiveness of certain measures and will comment on the value of such sensitivity analyses in the later parts of this report.

Analysis of Program A

In order to demonstrate our methodology in reasonable detail, two candidate civil defense programs, identified as Programs A and B, will be analyzed by means of a hand calculation. The results will be compared with machine runs using the same assumptions.

As discussed in Section II, the analysis of a candidate program would begin by review of the budgeted program elements and allocation of these elements to the preparedness system and the operating system implied by the proposed activities. This process will be represented here by brief descriptions of the significant characteristics of the programs, as a basis for the estimates of effectiveness in terms of casualty reduction.

Program A is aimed at population protection under a counterforce attack. It has some capabilities that are to be generated by surge activities during a crisis. There are no plans for crisis relocation but it is assumed that 10 percent of the risk population spontaneously move to the nonrisk area. Thus, the program builds on the current CD posture but with additional funding to recoup some of the capabilities eroded during the past decade.

The survey and marking of best available and upgradable shelter, including all-effects protection in risk areas, is to be completed by the mid-1980s. Surge upgrading to an average PF 40 of space needed to shelter the population is assumed. No stocks are procured. Revised community shelter plans are funded. A cadre of shelter manager instructors is funded with plans to train at least one-third of the managers needed. A cadre of radiological defense officers is also funded, with additional training of monitors planned. Procurement of additional ratemeters and dosimeters is funded. Matching of funds for local EOCs is resumed as well as some exercising of staffs. Matching fund support for current State and local warning systems is continued and National Warning System coverage is extended to broadcast stations. Emergency public information activities are well supported.

Table 8 shows the manual version of the assessment of Program A under attack 6A for the risk area. The left-hand column contains a series of events in the defense scenario at which an accounting of changes in population vulnerability occurs. These events should be read as "At the End of ______."

Table 8

CASUALTY ASSESSMENT TABLE FOR RISK AREA UNDER PROGRAM A (IN-PLACE)
Fraction or Percent of Population in Various Locations During Emergency
(Population 140,485,471 After 10% Spontaneous Evacuation)

Event	Home Basements		Stay-Puts		In Open	In Public Shelter (Categories A to X): A		B/C		E/F		G/H/I		X	
	Stay	Move	Stay	Move		Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.334					.044		.283		.037		.025		.277	
Warning	.334		.067		.060	.036		.230		.030		.020		.223	
Detonation	.077	(23%)	.004	(6.5%)	-0-	.024	(65%)	.053	(23%)	.005	(17%)	.002	(9%)	.020	(9%)
Fire	.038	(.039)	.002	(.002)	-0-	.024		.026	(.027)	.002	(.003)	.001	(.001)	.010	(.010)
D+1 (R)		.013		.0007	-0-				.009		.001		.0003		.003
(N)		.026		.0013	-0-				.018		.002		.0007		.007
Water	.011	(.027)	.002		-0-	--	(.024)	--	(.026)	--	(.002)	--	(.001)	--	(.010)
D+2 (R)		.009					.008		.009		.001		.0003		.003
(N)		.018					.016		.017		.001		.0007		.007
(Vent)															
Emergence	--	(.011)	--	(.002)	-0-	--		--		--		--		--	
D+14 (R)		.004		.001											
(N)		.007		.001											
Survivors	R	N	R	N		R	N	R	N	R	N	R	N	R	N
D+1	.009	.008	.0002	.0004				.008	.009	.0008	.0007	.0003	.0003	.0027	.0028
D+2	.006	.007				.008	.010	.009	.011	.0008	.0009	.0003	.0003	.0029	.0035
D+14	.003	.005	.0002	.0005											
Subtotals	.018	.020	.0004	.0009	-0-	.008	.010	.017	.020	.0016	.0016	.0006	.0006	.0056	.0063
Survivors	.038	(11%)	.0013	(2%)	(0%)	.018	(50%)	.037	(16%)	.003	(10%)	.0012	(6%)	.012	(5%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after.
R = Remedial movement; N = No remedial movement.

Thus, Shelter Assignment is assessed at the completion of the CSP process and shows where the population is planned to be sheltered. Similarly, Warning indicates the status of tactical movement to shelter just before detonations occur.

The shelter assignment has been obtained from machine runs by DCPA in which the availability of various kinds of shelter is matched against the resident population, grid square by grid square. In each grid square, people are assigned first to Category A public shelter and then to Category B/C shelter. It can be seen that in the Program A risk area, 0.327 or about one-third of the population can be sheltered in A, B, and C shelter. At this point, the portion of the remaining two-thirds having home basements are assigned to them. Since approximately half of the residences in the United States have basements, another one-third (0.334) of the population is assigned at this step. The remaining one-third (0.339) is assigned to the lower-grade public shelter. However, only about 6 percent can be sheltered in identified shelter. Most (27.7 percent, shown under column X of Table 8) are assigned to buildings upgraded to an average PF 40 in the crisis. The shelters labeled X are assumed to have the same blast protection as the most vulnerable class in Table 7 -- i.e., an MLOP of 5 and an MCOP of 2 psi.

The next line of Table 8, the Warning event, represents our estimate of the degree to which the planned shelter assignment can be carried out. First, we judge that emergency public information during the crisis is sufficient to assure that families assigned to their own home basements will go there upon being warned. (The basis for this judgment and other assumptions in these demonstrations of the method are discussed in Section IV.) With regard to the two-thirds of the risk population assigned to public shelter, we estimate that 10 percent will not go for behavioral reasons noted previously. These people amount to 6.7 percent of the risk population (10% of two-thirds) and are shown under Stay-puts in the Warning row of Table 8.

Thus, only 60 percent of the risk population are expected to move to shelter. Of these, it is estimated that 10 percent (6 percent of the risk population) will be still in the streets at the time of detonation. These are shown under In Open in Table 8. Their vulnerability to direct effects is assumed to be expressed by an MLOP of 2 psi and an MCOP of 1 psi. Survivors

of direct effects are assumed to proceed to the assigned shelter for fallout protection. The fraction of the risk population staying in each class of public shelter is then assumed to be proportional to the shelter assignment.

The "Detonation" event in Table 8 is the point at which direct effects fatalities are assessed. (A similar assessment table is used to assess injuries.) The "Stay" (in shelter) entries are the survivors. Adjacent to each entry is the percentage survival in parentheses. These are drawn directly from the bottom line of Table 4. Thus, home basements, which are rated at 10 psi MLOP, have 23 percent survivors. Stay-puts are assigned the same vulnerability as the population in the No Civil Defense case above -- 4 psi MLOP. Since there are no persons in the risk areas who experience less than 2 psi, all persons in the open at the time of detonation are fatalities according to the "cookie-cutter" procedure. On the other hand, there are no direct effects fatalities in the nonrisk area, although there are blast injuries in the 1 to 2 psi regions. In Table 8, no survivors are shown In the Open beginning with the detonation event. The survival rates in public shelters are those from Table 4 for the MLOPs given in Table 7.

The next event in the defense scenario is labelled Fire. This event accounts for the likelihood of fire growth and spread within the 2 psi region (the whole risk area) over the next several days after detonations. The amount of fire spread depends partly on the builtupness of the risk areas and partly on the effectiveness of fire suppression efforts by the survivors. We do not assume any fire fatalities in addition to those killed in the detonations. We do estimate that half of the risk population in shelter will be forced to leave because of the fire threat, with the exception of those in Category A shelters (subways, mines, and caves), which are not considered to be vulnerable to the fire threat. With that exception, the population staying in shelter in each category is reduced by half. The other half is shown in the "Move" column in parentheses. The average time of shelter emergence for this group is taken to be one day after detonation, as indicated in the Event column below the Fire entry.

Among the people who are forced into premature shelter emergence, we consider two alternative environments. First, they may take refuge in some structure in the vicinity at an average PF of 5 indefinitely. These people are labelled N -- for No Remedial Movement -- and will be assessed on the basis

of the D+2 curve in Figure 9. On the other hand, some refugees from the fire threat may be able to reduce their fallout radiation vulnerability markedly. The dominant countermeasure is remedial moving, in which people move or are transported to an area where the radiation intensity is very much lower than the environment where they were sheltered. Variations of a factor of 10 in dose rate are to be expected within miles upwind or crosswind of major targets and within a hundred miles or so in most other instances. Moving to an area of lower hazard is equivalent to having increased fallout protection. Hence, we attribute to successful remedial movement a post-shelter PF of 50 (10 x PF 5). At the same time, we assess a four-hour movement dose at a low PF (of 3) in a radiation field that is the average of the fields at the origin and destination of the movement. The effective PF curves for this situation are shown in Figures 11 and 12.

Other countermeasures can give the approximate same result as remedial movement. Decontamination, for example, can achieve a tenfold reduction in the radiation hazard in place. Some refugees can find shelter nearby that is equal to that which they left. These outcomes are subsumed here under the term Remedial Movement and people assigned this environment are labelled R in Table 8.

Except for random accidents, remedial movement requires a surviving radiation monitoring capability, a surviving direction and control capability, some shelter organization, and communications. For Program A, we estimate that remedial movement or its equivalent would be successful only one-third of the time; hence, one-third of those who must move are identified as R and two-thirds as N. This factor is applied uniformly to those in public shelters and in home basements, and to stay-puts.

The next scenario event that alters the vulnerability of some of the risk population is Water -- i.e., lack of drinking water. This lack is assumed to force the emergence, at D+2, of all remaining in public shelter. In residences, water is assumed to be available in hot water tanks, toilet tanks, and the like if the attack environment is less than 4 psi; otherwise, these resources are considered lost because of blast damage.

Because of our cookie-cutter assessment technique, all surviving stay-puts are in areas less than 4 psi and do not lack water. According to Table 4, 23 percent of the people in home basements survive, of which 6.5/23 or 28 percent

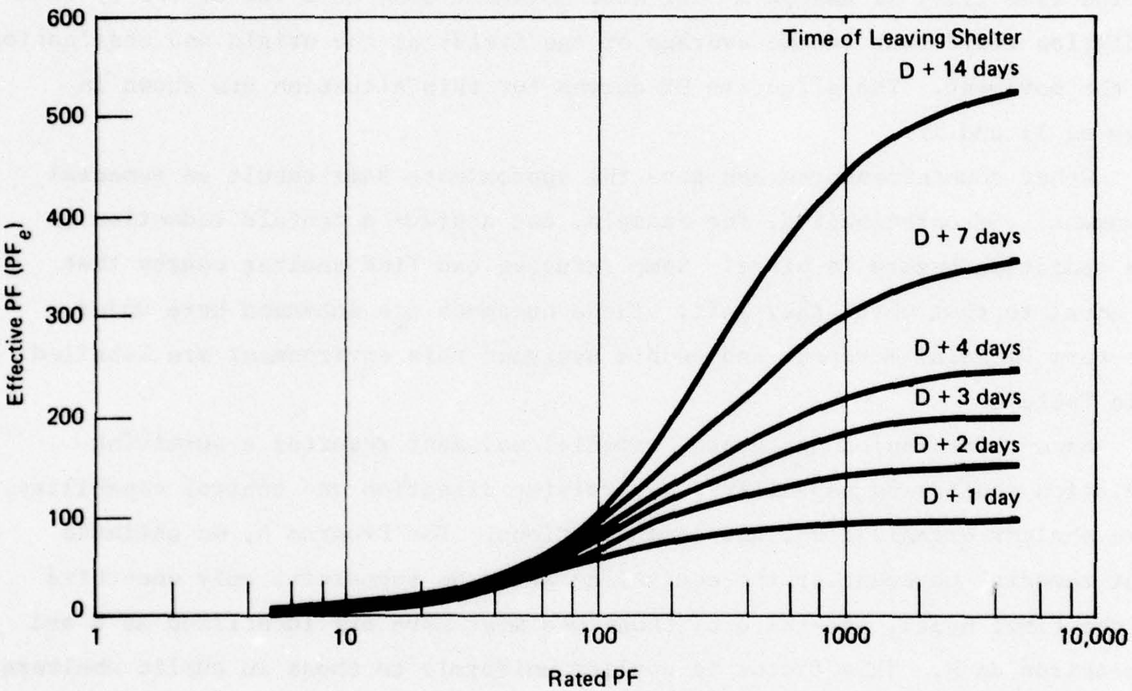

Figure 11 EFFECTIVE PF FOR FOUR-HOUR REMEDIAL MOVING AND FALLOUT ARRIVAL TIME OF ONE HOUR

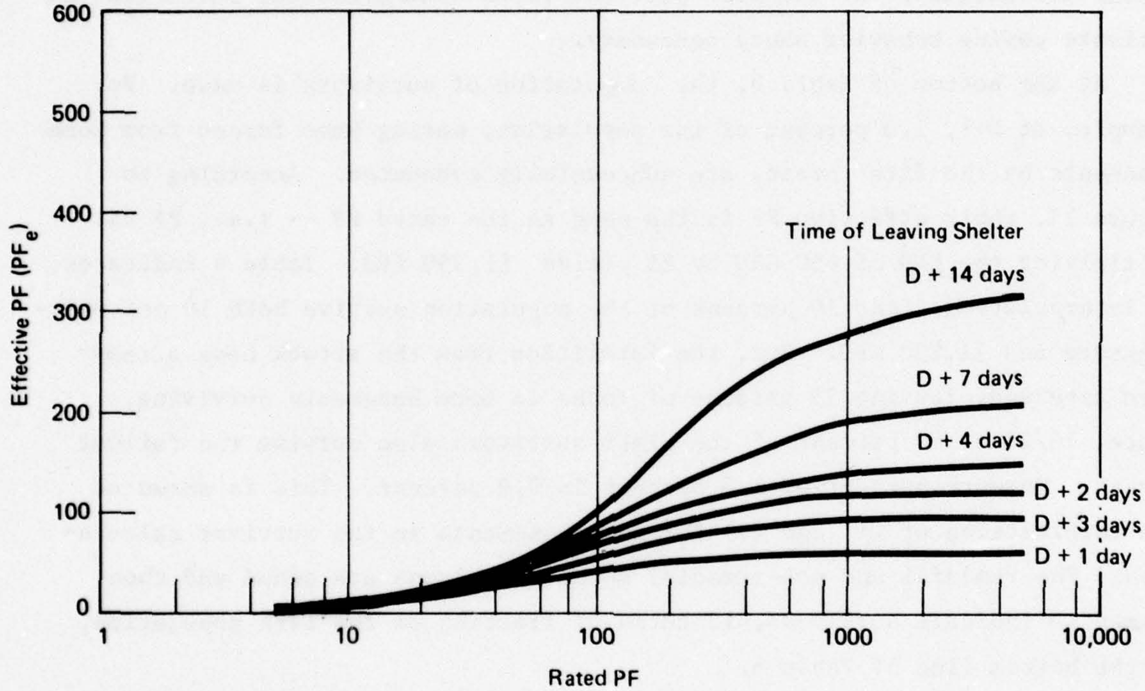

Figure 12 EFFECTIVE PF FOR FOUR-HOUR REMEDIAL MOVING AND FALLOUT ARRIVAL TIME OF FIVE HOURS

are in areas experiencing less than 4 psi. Thus, those staying in home basements because they do not lack drinking water are 28 percent of those still in home basements after the fire threat.

After the second day, the only people in shelter are those remaining in home basements and the remaining stay-puts. Thus, other potential events in the defense scenario, such as inadequate ventilation, do not occur, and hence, the "Vent" row in Table 8 contains no entries. The final event listed in Table 8 is Emergence -- i.e., shelter emergence, which is taken to be two weeks after attack. Those that remain in shelter are in residences where stocks are adequate for the most part and radio communications sufficient to motivate coping behavior where necessary.

At the bottom of Table 8, the computation of survivors is made. For example, at D+1, 1.3 percent of the population, having been forced from home basements by the fire threat, are successfully evacuated. According to Figure 11, their effective PF is the same as the rated PF -- i.e., PF 25. Multiplying the MLD of 450 ERD by 25 yields 11,250 ERD. Table 4 indicates, by interpolation, that 16 percent of the population survive both 10 psi overpressure and 11,250 ERD. But, the fatalities from the attack have already been assessed, leaving 23 percent of those in home basements surviving. Hence, 16/23 or 70 percent of the blast survivors also survive the fallout threat. Seventy percent of 1.3 percent is 0.9 percent. This is shown at the intersection of D+1 and (R) for home basements in the survivor calculation. The remedial and non-remedial movement columns are added and then summed to indicate survivors, in terms of fraction of the risk population, in the bottom line of Table 8.

It will be noted that 11 percent of those assigned to home basements survive both direct effects and fallout irradiation in attack 6A. Two percent of the stay-puts survive, the same as in the No Civil Defense case. None of those caught in the open survive. In public shelter, survival is 50 percent in Category A shelters, 16 percent in B/C shelters, and less than in home basements in each of the remaining categories. By adding up all of the surviving fractions across the bottom line, we obtain 11 percent as the survival rate in the risk areas, as compared for example to the 2 percent for the No Civil Defense case. Thus, Program A produces over five times the survivors in the risk areas against an attack for which it was not designed.

The comparable assessment for the nonrisk areas is shown in Table 9. There is no "In Open" column since none of the population experiences more than 2 psi. (However 9.1 percent of the population of the nonrisk area are blast injuries according to Table 5.) The shelter assignment is accomplished by machine computation as discussed for the risk area. Note that over half the population, which includes a 10 percent spontaneous evacuation from the risk areas, are sheltered in crisis-upgraded fallout shelters, Category X.

As before, we judge that 10 percent of those assigned to public shelters do not go, resulting in the warning situation shown. There are no fatalities resulting from direct effects of attack; hence, the distribution of the population in shelter does not change. There is also no fire threat. The first significant event is the lack of drinking water. Shelters are not stocked. However, there is no physical damage. In this case, we judge that all residences have sufficient potable water. Further, it is estimated that half of those in public shelter have drinking water from static water supplies, water trapped in tanks, and so on. Of the half of the public shelter population forced to emerge prematurely at D+2, we estimate that one-third can be moved and two-thirds cannot.

Because one-half of the public shelters are still occupied, lack of ventilation will become a problem in some shelters. These are the basement shelters, Categories A, B, and C. (There are also some basement shelters in the G/H/I category but the data available do not permit us to break them out.) Whether natural ventilation will be adequate to maintain a habitable shelter environment depends on the season of the year in which the attack occurs. Figure 13 shows the probability that basement shelters will remain tenable without some form of ventilation device. Shelters will remain tenable over 60 percent of the year in Montana and North Dakota, and less than 10 percent of the time in south Texas and Florida. In a detailed analysis, one could assign a probability to each grid square in the computerized assessment. For present purposes, we have chosen 40 percent as representing a reasonable average. That is, shelterees in public basement shelters (Categories A, B, and C) would be forced to abandon their protection at an average time of D+3 days with a probability of 60 percent. To reflect this situation, we move 60 percent of these people at D+3 in Table 9. The remaining sheltered population then emerges at two weeks. In all cases, only one-third execute remedial movement.

Table 9

CASUALTY ASSESSMENT TABLE FOR NONRISK AREA UNDER PROGRAM A (IN-PLACE)
Fraction or Percent of Population in Various Locations During Emergency
(Population 71,226,998 After Receiving 10% Increase by Spontaneous Evacuation)

Event	Home Basements		Stay-Puts		In Public Shelter (Categories A to X): A		B/C		E/P		G/H/I		X	
	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.337				.009		.086		.003		.012		.553	
Warning	.337		.066		.008		.077		.003		.011		.498	
Detonation	.337		.066		.008		.077		.003		.011		.498	
Water	.337		.066		.004	(.004)	.038	(.039)	.002	(.001)	.005	(.006)	.249	(.249)
D+2 (R)						.001		.013		.0003		.002		.083
(N)						.003		.026		.0007		.004		.166
Ventilation	.337		.066		.002	(.002)	.015	(.023)	.002		.005		.249	
D+3 (R)						.001		.008						
(N)						.001		.015						
Emergence		(.337)		(.066)		(.002)		(.015)		(.002)		(.005)		(.249)
D+14 (R)		.112		.022		.001		.005		.001		.002		.083
(N)		.225		.044		.001		.010		.001		.003		.166
Survivors	R	N	R	N	R	N	R	N	R	N	R	N	R	N
D+2					.0013	.0018	.013	.0168	.0005	.0006	.0017	.0023	.077	.100
D+3					.0008	.0012	.0076	.0108						
D+14	.093	.176	.0125	.025	.0005	.0019	.0051	.0097	.0005	.0008	.0018	.0032	.077	.138
Subtotals	.093	.176	.012	.025	.0026	.0039	.0257	.0367	.001	.0014	.0035	.0055	.154	.238
Survivors	.269	(80%)	.037	(57%)	.0065	(81%)	.062	(81%)	.0024	(80%)	.009	(82%)	.392	(79%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after.
R = Remedial movement; N = No remedial movement

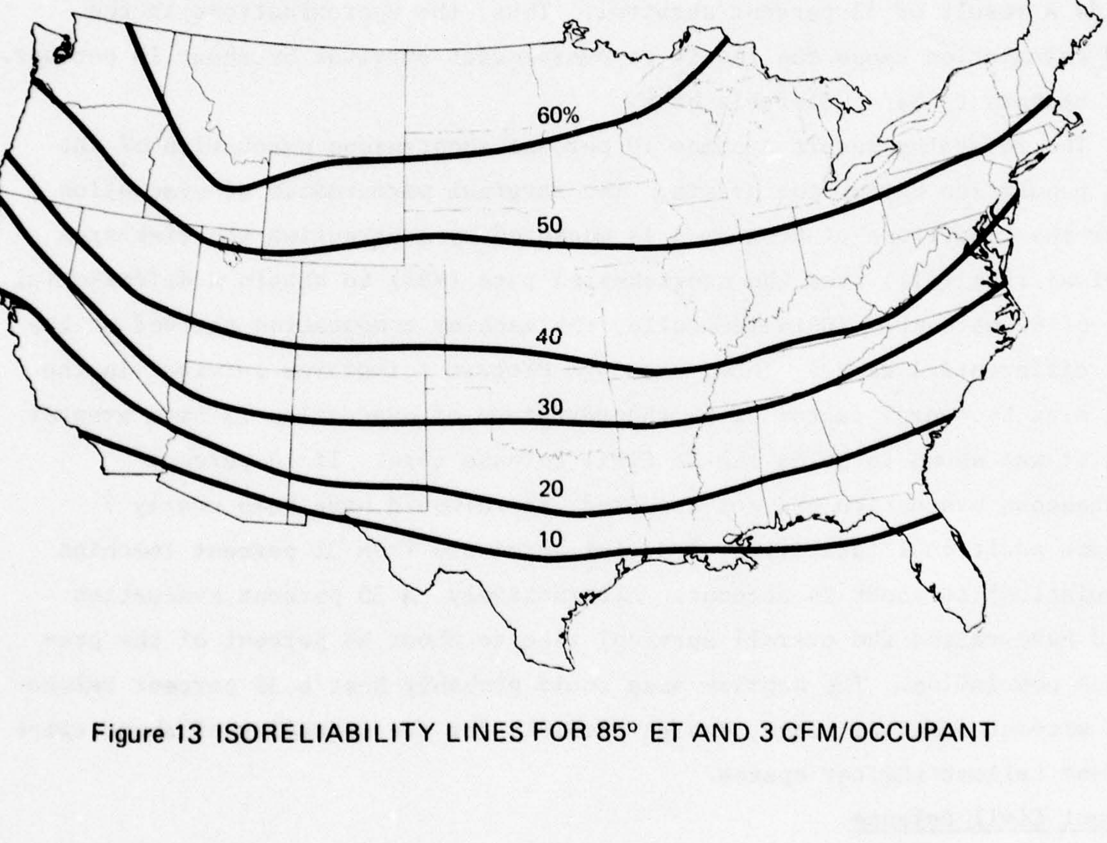

Figure 13 ISORELIABILITY LINES FOR 85° ET AND 3 CFM/OCCUPANT

The calculation of survivors is identical with that for the risk area except that Table 5 is used. Survival varies from 57 percent for stay-puts (same as in the No Civil Defense case) to 82 percent for the G/H/I shelters. The overall survival rate in the nonrisk area is obtained by adding up the survivors along the bottom line. It is 78 percent.

We can now compute the overall performance of Program A:

Risk area	0.11 x 140.5 =	15.5 million
Nonrisk area:	0.78 x 71.2 =	55.5 "
	Total Survivors =	71.0 million, or 34 percent of the preattack population.

The machine calculation of this analysis, using identical assumptions, yields a result of 31 percent survival. Thus, the approximations in the hand calculation cause the result to overpredict survival by about 10 percent. This appears to be a tolerable bias.

The foregoing result assumes 10 percent spontaneous evacuation of the risk population during the crisis. The marginal performance of evacuation under the conditions of Program A is measured by subtracting the risk-area survival rate (11%) from the nonrisk-area rate (78%) to obtain a differential risk of 67 percent. (Coincidentally, the machine computation arrived at the same differential risk.) Thus, although Program A improves survival in the risk area by over a factor of 5, the advantage of evacuation is even greater than it was shown to be in the No Civil Defense case. If 10 percent spontaneous evacuation had not occurred, there would have been nearly 7 percent additional fatalities, reducing survivors from 31 percent (machine calculation) to about 24 percent. Alternatively, a 30 percent evacuation would have raised the overall survival rate to about 44 percent of the preattack population. The nonrisk area could probably host a 30 percent relocation without specific plans, except possibly for the upgrading of about twice as many fallout shelter spaces.

Current Civil Defense

Program A is a substantial improvement over no civil defense, even if a majority of the population are fatalities in the 6A attack. There are 23 million additional survivors. Current civil defense would presumably provide some intermediate level of survival.

The performance of the current CD posture is somewhat difficult to characterize because a number of ostensible capabilities have been permitted

to decay and degrade to an indeterminate degree. Much of the performance under the 6A attack would depend on what repairs could be made during a surge period. Shelter use plans are out of date and do not account for blast vulnerability in risk areas. Nighttime warning is poor, and daytime warning is variable. As an approximation, we can estimate the performance of current civil defense by applying degradation factors to the Program A performance.

As in Program A, it is assumed that 10 percent of the risk population will evacuate spontaneously and that 10 percent will not cooperate (stay-puts). We will also assume that information and instructions during the surge period can motivate most of the population to seek shelter below ground in risk areas. The potential protection should be about the same as in Program A. However, lack of current plans, signs, and movement control will extend the time required for shelter-taking by at least 10 to 15 minutes. On this basis, we expect about 25 percent of the risk population to be in the streets at detonation rather than the 10 percent used in Program A. This is the important degradation factor in the risk area, resulting in a risk-area survival rate of 9.6 percent rather than 11 percent.

In the nonrisk area, the main degradation factor is the unlikelihood that any expedient or upgraded shelter will be produced because of lack of planning and other inhibiting factors. Thus, the half of the population in the X column of Table 9 would be assessed at a survival rate of 57 percent (as stay-puts) rather than at the 79 percent rate shown. The net effect is to make the overall survival rate in the nonrisk area about 60 percent.

The calculation for the current CD posture is:

Risk Area:	0.096	x	140.5	=	13.6	million
Nonrisk Area:	0.60	x	71.2	=	42.7	"
	Total Survivors			=	56.3	million

This result should be normalized for the bias in the manual calculation by multiplying by 31/34, the ratio of the machine calculation for Program A to the hand result, yielding 51.3 million survivors, or 24 percent of the preattack population.

Analysis of Program B

Program B, the second candidate program in this study, consists of a crisis relocation option and an in-place option based on best available shelter.

As in Program A, public shelter is to be augmented in both risk and nonrisk (host) areas by upgrading small commercial buildings to a PF of 40. In addition, the program calls for 9 million high-quality shelter spaces (MLOP 55 psi; MCOP 45 psi; PF 200) to be constructed during the surge period to house key workers after crisis relocation. We assume that about half of these spaces are actually available if crisis relocation is not directed, and that all are available if crisis relocation has been accomplished. These special shelters are assumed to be stocked. Otherwise, stocks are procured only for the host areas. Ventilation kits stocked in the host areas are adequate 90 percent of the year.

Program B includes a Federally funded survival system of EOCs, a CHAT* indoor warning capability, better communications, and more intensive training of shelter managers and radiological defense personnel.

The casualty assessment table for the risk area is Table 10. This calculation assumes that, although there is a crisis relocation plan for every risk area, the President does not order the plan carried out before the attack. We believe, however, that the fact that relocation plans exist will be discussed widely during the crisis and will encourage a larger spontaneous evacuation than otherwise. Our estimate is 15 percent. The residual population in the risk area is 132.7 million, as shown on Table 10.

Shelter assignment follows the same priority as in Program A: highest blast protection first. The first shelters to be allocated are the 55-psi key-worker shelters, identified as "Y" shelters in Table 10, followed by the "A" and "B/C" categories. Because of the somewhat larger availability of good shelter, the fraction of the population with home basements at the time of assignment is reduced to about 32 percent. The "X" shelters are buildings upgraded to an average PF 40, as in Program A.

We again assume that 10 percent of those assigned to public shelter do not go at the time of warning. However, the provision of a television-based wake-up warning system (CHAT) and the increased efforts devoted to expediting tactical moving lead us to estimate that few, if any, of the risk population would be in the streets at the time of attack. Thus, the public shelters are

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* CHAT (Crisis Home Alert Technique) is a procedure for using home television sets as an alerting and informing medium. The population is instructed to keep their sets on at all times. Volume is controlled from the TV stations to wake people up at night.

Table 10

CASUALTY ASSESSMENT TABLE FOR RISK AREA UNDER PROGRAM B (IN-PLACE)
Fraction or Percent of Population in Various Locations During Emergency
(Population 132,680,723 after 15% Spontaneous Evacuation)

Event	Home Basements		Stay-Puts		In Open	In Public Shelter (Categories A to Y) A		B/C		E/F		G/H/I		X		Y	
	Stay	Move	Stay	Move		Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.319					.044		.283		.037		.025		.256		.036	
Warning	.319		.068		-0-	.040		.255		.033		.023		.230		.032	
Detonation	.073	(23%)	.004	(6.5)		.026	(65%)	.059	(23%)	.006	(17%)	.002	(9%)	.021	(9%)	.024	(75%)
Fire	.037	(.036)	.002	(.002)		.026		.030	(.029)	.003	(.003)	.001	(.001)	.010	(.011)	.024	
D+1 (R)		.024		.0014					.019		.002		.0007		.007		
(N)		.012		.0007					.010		.001		.0004		.004		
Water	.010	(.027)	.002			-0-	(.026)	-0-	(.030)	-0-	(.003)	-0-	(.001)	-0-	(.010)	.024	
D+2 (R)		.018					.017		.020		.002		.0006		.006		
(N)		.009					.009		.010		.001		.0003		.004		
Emergence		(.010)		(.002)													(.024)
D+14 (R)		.007		.0014													.016
(N)		.003		.0007													.008
Survivors	R	N	R	N		R	N	R	N	R	N	R	N	R	N	R	N
D+1	.017	.004	.0005	.0002		-	-	.019	.005	.002	-	.001	-	.006	.001	-	-
D+2	.013	.004	-	-		.017	.006	.019	.006	.002	-	.001	-	.006	.002	-	-
D+14	.005	.002	.0005	.0002		-	-	-	-	-	-	-	-	-	-	.016	.007
Subtotals	.035	.010	.001	.0004		.017	.006	.038	.011	.004	-	.002	-	.012	.003	.016	.007
Survivors	.045	(14%)	.0014	(2%)		.023	(58%)	.049	(19%)	.004	(13%)	.002	(8%)	.015	(6%)	.023	(73%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after.

R = Remedial movement; N = No remedial movement

occupied to 90 percent of their assigned capacity. Fatalities are assessed at detonation, based on the attack environment matrix in Table 4.

Half of the shelters are presumed to become untenable because of the fire threat, except for Category A and Y shelters. In contrast to Program A, our evaluation of the survivable direction and control elements and RADEF monitoring capability lead us to estimate that remedial movement could be carried out in two out of three cases in both risk and host areas. This judgment is reflected in the allocation of people who move to the R and N categories.

Lack of drinking water for people in residences is evaluated just as in Program A. Since only the "Y" shelters are presumed stocked, all remaining public shelters are abandoned at D+2. Therefore, there is assumed to be no difficulty with the later occurring ventilation problem in the special "Y" shelters or residences. These people emerge at the end of two weeks.

The survival calculation proceeds as in the Program A example. The sum of the survivors along the bottom line, indicates that the survival rate in risk areas would be about 16 percent.

The corresponding assessment for the nonrisk area is shown in Table 11. The shelter assignment used is the same as for Program A. The warning and detonation vulnerabilities are also the same. Since shelter stocks, including water and ventilation, are procured in Program B, the only degradation in the system is that the ventilation kits are adequate only 90 percent of the time. Hence, 10 percent of the population in category A, B, and C shelters would need to emerge prematurely. Our estimate of the timing is D+7. Otherwise, all shelterees emerge at the end of two weeks. Remedial movement is successful two out of three times. The sum of the survivor fractions along the bottom line gives 86 percent as the overall survival rate in the nonrisk area.

The fatality calculation for Program B in the in-place option under attack 6A is:

Risk Area:	0.162 x 132.7 =	21.5 million
Nonrisk Area:	0.857 x 79.1 =	67.8 "
	Total Survivors =	89.3 million

This result should be normalized to the Program A run comparison by multiplying by 31/34 to yield 81.4 million survivors, or 38 percent of the preattack

Table 11

CASUALTY ASSESSMENT TABLE FOR NONRISK AREA UNDER PROGRAM B (IN-PLACE)
Fraction or Percent of Population in Various Locations During Emergency
(Population 79,088,760 After 15% Increase by Spontaneous Evacuation)

Event	Home Basements		Stay-Puts		In Public Shelter (Categories A to X): A		B/C		E/F		G/H/I		X	
	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.337				.009		.086		.003		.012		.553	
Warning	.337		.066		.008		.077		.003		.011		.498	
Detonation	.337		.066		.008		.077		.003		.011		.498	
Ventilation	.337		.066		.007	(.001)	.069	(.008)	.003		.011		.498	
D+7 (R)						.001		.005						
(N)						--		.003						
Emergence		(.337)		(.066)		(.007)		(.069)		(.003)		(.011)		(.498)
D+14 (R)		.225		.044		.005		.046		.002		.007		.332
(N)		.112		.022		.002		.023		.001		.004		.166
Survivors	R	N	R	N	R	N	R	N	R	N	R	N	R	N
D+7	-	-	-	-	.001	-	.005	.003	-	-	-	-	-	-
D+14	.187	.087		.012	.005	.002	.046	.023	.002	.001	.007	.003	.310	.138
Subtotals	.187	.087	.025	.012	.006	.002	.051	.026	.002	.001	.007	.003	.310	.138
Survivors	.274	(81%)	.037	(57%)	.008	(100%)	.077	(100%)	.003	(100%)	.010	(90%)	.448	(90%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after.
R = Remedial movement; N = No remedial movement.

population. No machine run was made for this case, as the posture is very similar to that of Program A.

The assessment of the crisis relocation option of Program B is shown in Tables 12 and 13. The assessment assumes that 80 percent of the risk population will have evacuated to the nonrisk area. Actually, on-shift key workers make up 30 percent of the people remaining in the risk area. They are assigned to the "Y" shelters, which are assumed to have been constructed and stocked before the attack. Another 35 percent of the much reduced risk-area population are assigned to the A, B, and C shelters. Of the remainder, about half have home basement shelter. We assume that the key workers and those with home basements seek shelter upon warning. Ten percent of the others do not go to public shelter (stay-puts). The remainder of the risk-area assessment follows the previous discussion, with remedial movement being successful two-thirds of the time. The overall survival rate in the risk area, obtained by summing across the bottom line, is about 34 percent.

In the host area, the fraction of the enlarged population in home basements is greatly reduced because residents are a minority of the population. Basement sharing is not assumed. Most of the population is assigned to upgraded X shelter. Again, it is assumed that 10 percent of those assigned to public shelter are stay-puts. The only early emergence is the 10 percent chance that ventilation will be inadequate in large basement shelters and in the upgraded shelters. We estimate that remedial movement is almost always successful because of the relatively late emergence at seven days and because of the increased capabilities brought to the host area by relocated organizations. The overall survival rate in the nonrisk area is about 91 percent.

The fatality calculation for Program B in the relocated mode under attack 6A is:

Risk Area:	0.342 x 31.9 =	10.9 million
Nonrisk Area:	0.911 x 179.8 =	163.8 "
	Total Survivors =	174.7 million,

or 83 percent of the preattack population. The detailed machine run for this posture calculated 172.0 million survivors or 81.2 percent of the preattack population. The approximate hand calculation turns out to be high by about 2 percent.

Injury Assessment

The assessment of injuries follows a similar pattern to that demonstrated for the fatality calculations. Since the vulnerability functions define total

Table 12

CASUALTY ASSESSMENT TABLE FOR RISK AREA UNDER PROGRAM B (80% EVACUATION)
Fraction or Percent of Population in Various Locations During Emergency
(Population 31,909,386 After 80% Evacuation)

Event	Home Basements		Stay-Puts		In Public Shelters (Categories A to Y) A		B/C		E/F		G/H/I		X		Y	
	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.20				.06		.29		.02		.01		.12		.30	
Warning	.20		.05		.054		.261		.018		.009		.108		.30	
Detonation	.046	(23%)	.003	(6.5%)	.035	(65%)	.06	(23%)	.003	(17%)	.001	(9%)	.010	(9%)	.226	(75%)
Fire	.023	(.023)	.0015	(.0015)	.035	-0-	.03	(.03)	.0015	(.0015)	.0005	(.0005)	.005	(.005)	.226	-0-
D+1 (R)		.015		.001				.02		.001		.0003		.003		
(N)		.008		.0005				.01		.0005		.0002		.002		
Water	.006	(.017)	.0015		-0-	(.035)	-0-	(.03)	-0-	(.0015)	-0-	(.0005)	-0-	(.005)	.226	-0-
D+2 (R)		..011				.023		.02		.001		.0003		.003		
(N)		.006				.012		.01		.0005		.0002		.002		
Emergence	-0-	(.006)	-0-	(.0015)											-0-	(.226)
D+14(R)		.004		.001												.151
(N)		.002		.0005												.075
Survivors	R	N	R	N	R	N	R	N	R	N	R	N	R	N	R	N
D+1	.010	.006	.0003	.0001	-	-	.020	.005	.001	-	.0003	-	.003	.001	-	-
D+2	.008	.002	-	-	.023	.008	.020	.006	.001	-	.0002	.0001	.003	.001	-	-
D+14	.003	.001	.0003	.0002	-	-	-	-	-	-	-	-	-	-	.150	.069
Subtotal	.021	.009	.0006	.0003	.023	.008	.040	.011	.002	-	.0005	.0001	.006	.002	.150	.069
Survivors	.03	(15%)	.0009	(2%)	.031	(57%)	.051	(19%)	.002	(13%)	.0006	(7%)	.007	(6%)	.219	(73%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after
R = Remedial movement; N = No remedial movement.

Table 13

CASUALTY ASSESSMENT TABLE FOR NONRISK AREA UNDER PROGRAM B (80% EVACUATION)
Fraction or Percent of Population in Various Locations During Emergency
(Population 179,864,207 After 80% Increase by Crisis Relocation)

Event	Home Basements		Stay-Puts		In Public Shelter (Categories A to X): A		B/C		E/F		G/H/I		X	
	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move	Stay	Move
Shelter Assignment	.133				.003		.017		.002		.01		.835	
Warning	.133		.087		.003		.015		.002		.009		.751	
Detonation	.133		.087		.003		.015		.002		.009		.751	
Ventilation	.133		.087		.0027	(.0003)	.0135	(.0015)	.002		.009		.676	(.075)
D+7 (R)						.0003		.0015						.075
(N)						--		--						--
Emergence	--	(.133)	--	(.087)	--	(.0027)	--	(.0135)	--	(.002)	--	(.009)	--	(.676)
D+14 (R)		.133		.087		.0027		.0135		.002		.009		.676
(N)		--		--		--		--		--		--		--
Survivors	R	N	R	N	R	N	R	N	R	N	R	N	R	N
D+7	-	-	-	-	.0003	-	.0015	-	-	-	-	-	.072	-
D+14	.110	-	.050	-	.0027	-	.0135	-	.002	-	.009	-	.650	-
Survivors	.11	(83%)	.05	(57%)	.003	(100%)	.015	(100%)	.002	(100%)	.009	(100%)	.722	(96%)

D = Detonation time; D+1 is 1 day after detonation; D+14 is 14 days after.
R = Remedial movement; N= No remedial movement.

casualties, it is necessary to compute casualties and then subtract the corresponding fatalities to obtain injuries. The hand calculation is complex and is not presented here. The machine program, which assesses both fatalities and injuries, uses about 30 minutes of central processor time for a national run. For Program A, the machine computation arrived at 31 percent survivors and 21 percent uninjured survivors. For the Program B relocated mode, survivors numbered about 81 percent and uninjured survivors about 68 percent. It is clear that the consequences of a heavy nuclear attack can range from less than 20 percent survival to over 80 percent survival, depending upon the performance of civil defense. It seems important, then, to examine the performance of programs and their components as carefully and as objectively as possible to provide a guide to policy-making.

IV. BASIS FOR QUANTIFICATION

Background

The validity of estimates of CD operating system effectiveness depends in significant part on the ability to quantify the key factors in the calculation, such as the fraction of stay-puts, the time of shelter emergence because of lack of water, and the like. Useful estimates of the cost per added survivor of individual program elements often require an even better understanding of the effect of preparedness activities on the vulnerability of the population. The purpose of this section is to summarize the basis for assigning values to the variables that enter into an effectiveness calculation.

Many possible events in the "defense scenario" have been omitted from the demonstration of the methodology in the previous section. Some of these events will be discussed here. Mainly, we will discuss the basis for our choice of values in these initial calculations and the uncertainties inherent in current data. We believe that the choices made are not unreasonable; nonetheless, because of the brief period devoted to this research, it has not been possible to do a thorough literature search and analysis of all applicable data and theory. The problem obviously deserves a more detailed scrutiny of the basis for quantification, and additional analysis and experiment where warranted.

But it should be said at the outset that the approach taken in this study is not unprecedented. During the 1960s, the Office of Civil Defense, predecessor to DCPA, engaged in a number of cost-effectiveness studies at the instigation of then Secretary of Defense Robert S. McNamara. These damage-limiting studies, as they were called, became increasingly sophisticated and tended to outrun the research data available. The 1967 damage-limiting study, DAL-67, not only evaluated the cost per added survivor of a range of candidate CD programs but also evaluated alternative warning systems and shelter stocks on the same basis. DAL-69 was the last of the damage-limiting studies. It also estimated the cost-effectiveness of warning and stocking programs. DAL-69 was the only study to attempt to include the vulnerability of the population to fire spread although the consideration of countermeasures was not undertaken.

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Since 1969, DCPA has not undertaken a formal cost-effectiveness study although it has participated in allied efforts, such as the PONAST studies of the Joint Chiefs of Staff. Considerable research was undertaken, however, during the late 1960s and early 1970s on various aspects of the problem. DCPA's current casualty assessment system is a product of this effort. One of the early conceptual efforts was undertaken by Hawkins[7] in 1967. His proposed framework was quite similar to our approach. Effectiveness was to be determined by comparing the number of casualties in a baseline "no countermeasure" prediction to that in which a countermeasure is assumed to operate. Two population groups were considered: those out-of-doors and those in buildings. The prediction program in essence successively subjected each group to the environments or hazards in the same order as they would occur. Cells approximately 1 kilometer square were estimated to be the necessary level of detail. The concept was never implemented, partly because it did not offer any specific methodology to accomplish what it proposed. The use of effective PF to account for survival in stocked and unstocked fallout shelters was, on the other hand, already in use by OCD in the damage-limiting studies.

Shelter Assignment

In the demonstration results of Section III, we used the DCPA population distributions because they were based on survey data evaluated at the grid-square level of detail. The DCPA assignments were made in order of blast vulnerability in the risk area and in order of fallout vulnerability in the nonrisk area. Other assignment procedures could have put more people in better shelters, and sometimes at less cost. For example, in Program A (and the current CD posture), the limitations of the movement-to-shelter countermeasure set led to the conclusion that about 10 percent of those going to public shelter in the risk area would be in the streets (i.e., in the open) at the time of detonation, and hence, extremely vulnerable to direct effects. An alternative assignment strategy would be to assign families with home basements to those basements first. Since about half of all households have residential basements, the fraction in home basements would be increased from one-third (Table 8) to about one-half. In turn, the fraction of stay-puts would be decreased from 6.7 percent to 5 percent, and the fraction in the open from 6 percent to 4.5 percent, according to our assumptions. Both stay-puts and people in the open would be much more vulnerable than those in home

basements. In addition, most of the remaining 13 percent of the risk population assigned to home basements would come from the "X" class upgraded shelters, both doubling the survival rate and reducing upgrading time and effort.

A weakness in the foregoing procedure is that the high quality shelter (A, B, and C categories) would not be fully assigned in the home-basement-rich states of the northern tier. That is, in many grid squares there would not be enough population without home basements to fill these shelters. In these cases, the assignment algorithm could reassign from home basements after those without basements were assigned.

A preliminary assessment indicates that an additional one percent of the risk population might survive in the Program A circumstances if alternative shelter assignment strategies were examined in light of the other events in the defense scenario. More survivors could be added in these circumstances by invoking home-basement sharing in the risk areas of the South and Southwest where residential basements are relatively few. These concepts have been the subject of behavioral research but have not been addressed in a cost-effectiveness analysis.

Warning and Movement

Warning behavior and movement control appear to be crucial only in the risk area. We assumed that those assigned to home basements would use them. There is ample research data to support this assumption. The basis for assuming that 10 percent of those assigned to public shelter would not go has a more tenuous basis, largely the interviewing by Warner and Christiansen of households in the Denver and Salt Lake City areas.[8] More study of this behavioral factor is warranted, especially the influence of knowledge of shelter stocking and shelter manager training on the credibility of public shelter use.

The significant feature of moving to shelter is its dynamics -- i.e., it involves changes with respect to time. For the evaluation, these changes can be set forth in a scenario that describes two independent sets of events:

- o Those that have to do with the movement of people into the shelters.
- o Those that have to do with the attack situation.

The scenario for the people has three significant events:

(a) The people are warned.
(b) The people are ready to go to shelter.
(c) The people arrive in shelter.

The activities that lead to these events each take some time to accomplish, and the time differs from person to person. The attack scenario has one significant event: the detonation of a weapon that subjects the people to direct weapon effects.

Three periods in the attack scenario are significant for the people:

(1) Warning: from the moment that the alert begins to the last moment at which a person decides to go to shelter.
(2) Preparing: from the moment at which the first person decides to go to shelter to the moment at which the last person completes his preparations for going.
(3) Moving: from the moment that the first person starts to move toward shelter to the moment that the last person arrives in shelter.

Because different people take different times for these activities, these periods overlap and the distributions of their lengths for the various people in the whole population must be ascertained and combined.

Warning Period

Warning includes alerting to gain attention and informing to tell what needs to be done. It has performed its mission when a prudent person is induced to act as intended. Moon[9] suggests that the warning process has several subordinate processes:

(1) Hear and recognize signal.
(2) Seek and find confirmation of signal meaning and validity.
(3) Relate signal to self.
(4) Decide to act.

For this discussion, the period required for this process is called "warning time."

Operations Research Inc. examined warning time experimentally by choosing about 100 families at random from the Atlanta telephone directory and calling them between midnight and 5:00 a.m. They measured the time from the first ring to the first spoken word.[10] They found that over 90 percent answered within one-half minute and all within one minute. Moon noted that the distribution found by ORI could be approximated by a relationship of the form: $f(t) = \alpha^2 t e^{-\alpha t}$, where f(t) is the distribution of warning times, t is the time after the alerting signal started, and α is a constant that defines the shape of the distribution. He then derived values of α for alternative warning methods by analogy to other situations and events. The following are of interest here:

(1) Radio Warning: in this method, an alert signal is given by radio or TV and a confirming message is given immediately by the same station. From the ORI data, Moon concluded that 90 percent of the people would respond to the alert signal within 0.5 minute and that this was probably the optimum length of the signal. He reasoned that by analogy to radio and TV commercials, 0.5 minute of informing would be effective. This would complete the warning message one minute after the alert signal started. Taking, as Moon did, that the maximum rate of warning would occur at this time, the appropriate value of α is 1.0 and this was used to calculate the summary distribution shown in Figure 14.

(2) Siren Alerting: in this method, the alerting signal is given by outdoor sirens and a confirming message is given by commercial radio and TV stations. In this case, there could be some delay between hearing the sirens and turning on the radio and finding the correct station. For this method there are two alternatives, both subject to the delay:
(a) Given a "surge" in CD preparedness activity, especially in Emergency Public Information, the people would more readily recognize and believe the sirens, and the radio stations would be ready to get the confirming message on the air immediately. This process is termed "simultaneous confirmation" and for it the value 0.33 was used for α as suggested by Moon.
(b) Without intensive Emergency Public Information efforts, people would recognize the siren signal more slowly and believe it more reluctantly. Radio stations would likely experience a delay of several minutes in getting the confirming message on the air. This process is termed "delayed confirmation" and for it the value 0.17 was used for α as suggested by Moon.

(3) No Alerting: in this method, the warning message is given by radio, TV, bull horn, door-to-door visit, and so on, but without any alerting signal. By analogy to flood warnings in the nighttime, Moon found the value of α for this case to be 0.0275. The summary distribution for this case -- which is equivalent to the "no civil defense case" -- is shown in Figure 14 for comparison to the alerting cases.

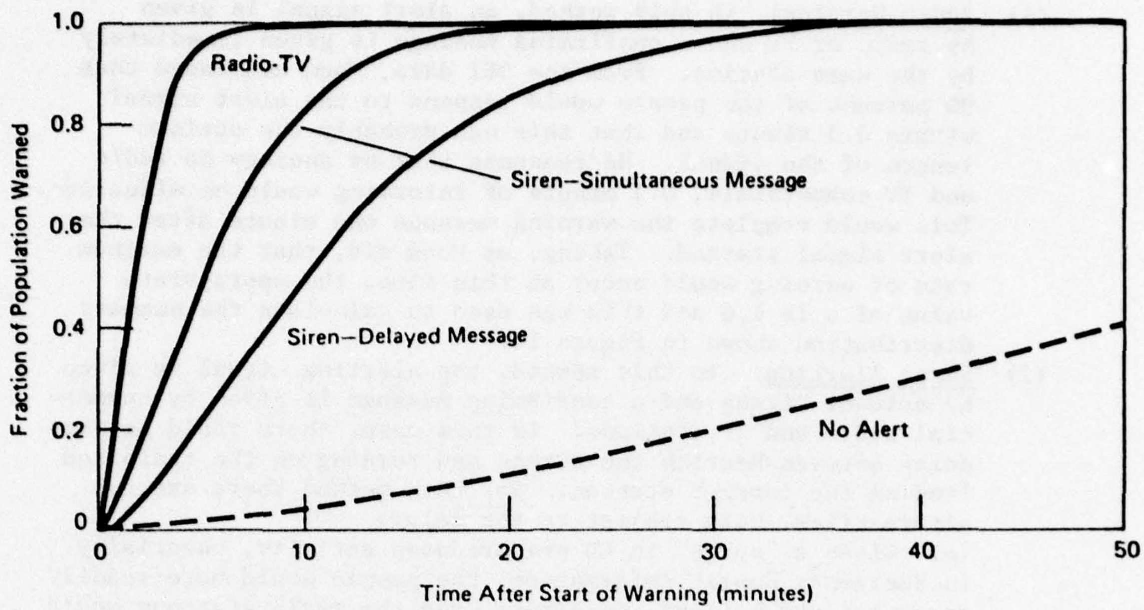

Figure 14 DISTRIBUTION OF WARNING TIMES

Preparing Period

When a person has decided to act, his next step is to prepare to act. The amount of time this preparation would take would depend on how much had been done in advance and how much left for the last minute. Operations Research Inc. also investigated preparation time experimentally[9]. They made arrangements with over 100 volunteer families, called them by telephone in the nighttime, and measured the time between the call and the arrival of the family at the curb outside their residence. Moon found that the form of the distribution for preparation time could be approximated by a relationship of the same general form as for warning time.

The people in the ORI experiment knew that they would be called although they did not know when the call would come. It is likely that they made advance preparations in order to "look good" when the time came. It seems, then, that the experimental conditions would reasonably represent the situation of a population after a "surge" of CD preparations. Therefore, the ORI data have been taken to be consistent with the radio and siren-simultaneous confirmation warning methods and were used without further manipulation.

It should be pointed out, however, that these experiments are generally oriented toward a nighttime warning situation. Daytime response should be considerably better and hence, the average response should be somewhat shorter than we have assumed. Moreover, siren coverage is far from complete in risk areas today and under the assumptions of Program A. Therefore, it would appear that there should be a greater spread between a radio-TV warning capability and the siren-alerting conditions.

Unprepared people would require longer preparation times. However, data for this case are not available and it would prove very difficult, if not impossible, to acquire them. For this analysis, preparation times for unprepared people were taken to be twice those for prepared people with the same form of distribution, and to be consistent with the "siren-delayed" case.

It was noted earlier that the warning period and the preparation period overlapped, at least in part. Therefore, the two sets of times cannot be simply added to find the distribution of "ready to move after the alert starts" times. The two distributions have to be convoluted probabilistically. The resultant combined distributions are shown in Figure 15.

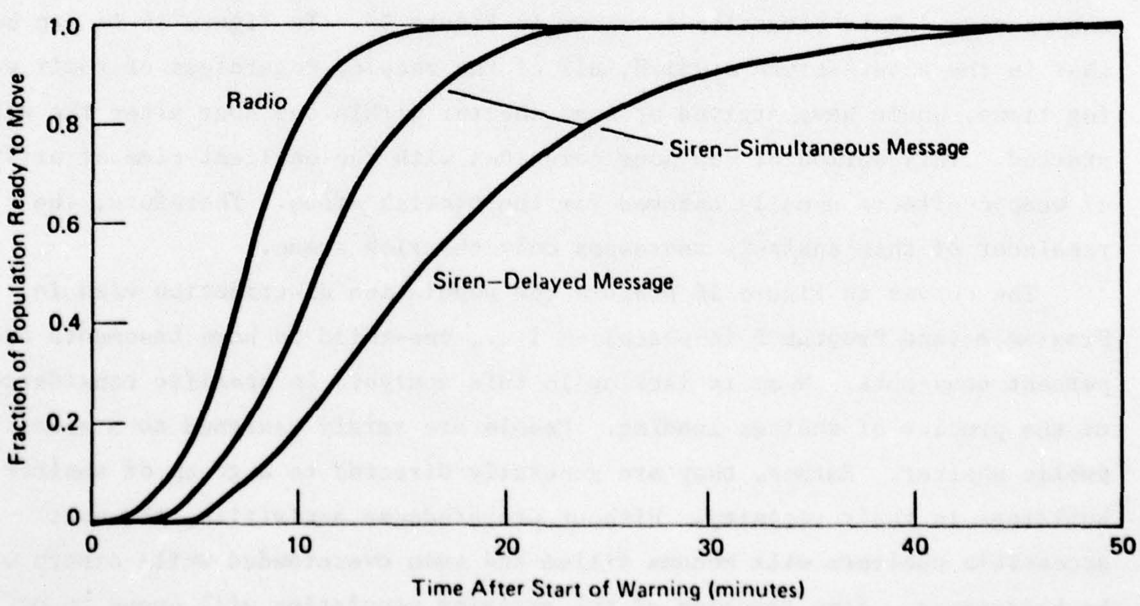

Figure 15 DISTRIBUTION OF STARTING TIMES

Moving Period

The third phase is the actual moving to shelter, taken to be walking for this discussion. In this casualty assessment method, people are assigned to shelters within a grid square of 2 minutes (latitude and longitude). Lacking information to the contrary, it seems reasonable to assume that the shelters are at the center of the area and that the people are uniformly distributed. For convenience in calculating, the grid square was rationalized into a circle one mile in radius. When this circle is divided into ten concentric rings, each 0.1 mile wide, the population distribution varies as the odd numbers: 0.01, 0.03, ... 0.19.

In connection with a study of shelter location, the Operations Research Office, Johns Hopkins University, studied walking speeds. They observed some 125 people on the streets of Washington. They concluded that walking speeds are normally distributed with a mean 85 yd/min and with 95 percent of them between 60 and 110 yd/min. For comparison: 85 yd/min is approximately 3 mi/hr which has often been used conventionally for average walking speed.

Given the distributions of starting times and walking-to-shelter times, it is possible to construct the part of the scenario that describes the location of the shelter-bound people minute-by-minute from the moment that the alert starts until they are all in shelter, provided that nothing interrupts the process. This situation is shown in Figure 16. In Figure 16 it can be seen that in the alternatives studied, all of the people, regardless of their starting times, would have arrived at some shelter within one hour after the alert started. This period of one hour coincides with the earliest time of arrival of weapon effects usually assumed for the nonrisk areas. Therefore, the remainder of this analysis addresses only the risk areas.

The curves in Figure 16 presume the population distribution used in Program A (and Program B in-place) -- i.e., one-third in home basements and 6.7 percent stay-puts. What is lacking in this analysis is specific consideration of the problem of shelter loading. People are rarely assigned to a specific public shelter. Rather, they are generally directed to a group of shelter buildings in their vicinity. Without preparedness activities, the most accessible shelters will become filled and even overcrowded while others will be half-empty. Some fraction of the arriving population will queue up or wander about looking for another shelter, thus protracting the period of

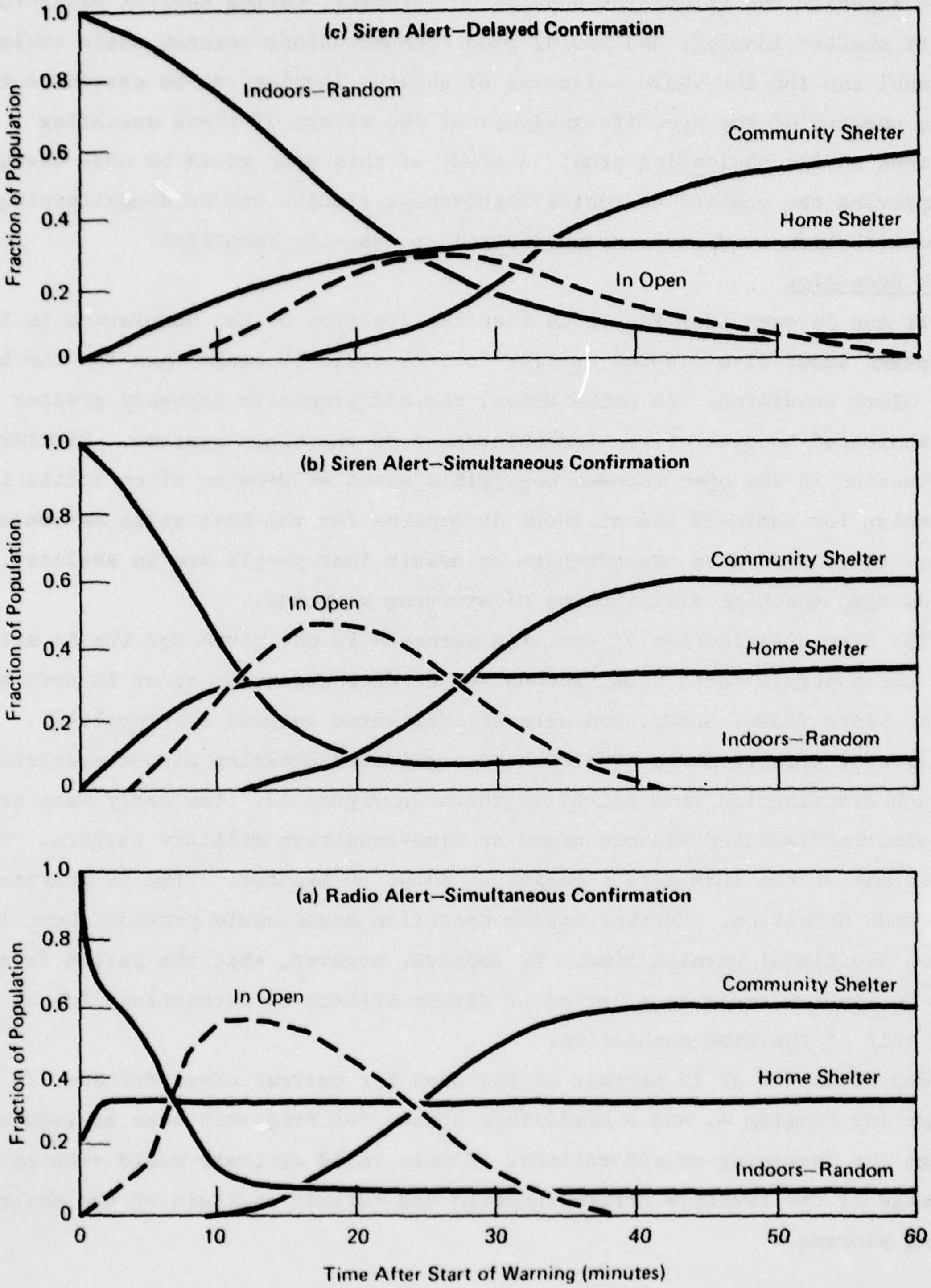

Figure 16 LOCATION OF PEOPLE DURING MOVE TO SHELTER

vulnerability in the open. This problem can be eased by having public safety forces expedite and direct the population movement, having shelter managers monitor shelter loading, and having good communications between these trained personnel and the EOC where balancing of shelter loading can be carried out. We are unaware of any specific analysis of the effect of these operating functions on the sheltering time. A study of this type would be most useful in improving the quality of cost-effectiveness studies and in demonstrating the contribution of direction and control to casualty reduction.

Attack Scenarios

It can be seen from Figure 16 that the fraction of the population in the open peaks about five minutes earlier for the radio-TV alert than for the best siren alert condition. As noted above, the difference is probably greater than indicated because of the incompleteness of the siren systems. Similarly, the fraction in the open becomes negligible about 40 minutes after initiation of warning for radio-TV and at about 45 minutes for the best siren estimate. Whether these responses are adequate to assure that people are in shelter depends upon the time distribution of arriving warheads.

The time distribution of arriving warheads is not given for the 6A attack. It is not possible for a simultaneous set of detonations to occur in such an attack, since ICBMs, SLBMs, and aircraft-delivered weapons are involved. Earlier cost-effectiveness studies have considered detailed attack scenarios. One such distribution from DAL-67 is shown in Figure 17. The early weapons are submarine-launched weapons aimed at time-sensitive military targets. The main weight of the ICBM attack begins at about 30 minutes. Time is measured from BMEWS detection. Current attack detection means would provide about 10 minutes additional warning time. It appears, however, that the period from 35 to 50 minutes could be a period of direct effects of detonations for at least half of the risk population.

Our estimates of 25 percent in the open for current civil defense, 10 percent for Program A, and a negligible number for Program B were arrived at through the foregoing considerations. A more valid estimate would require knowledge of the feasible attack scenario and further analysis of the shelter loading process.

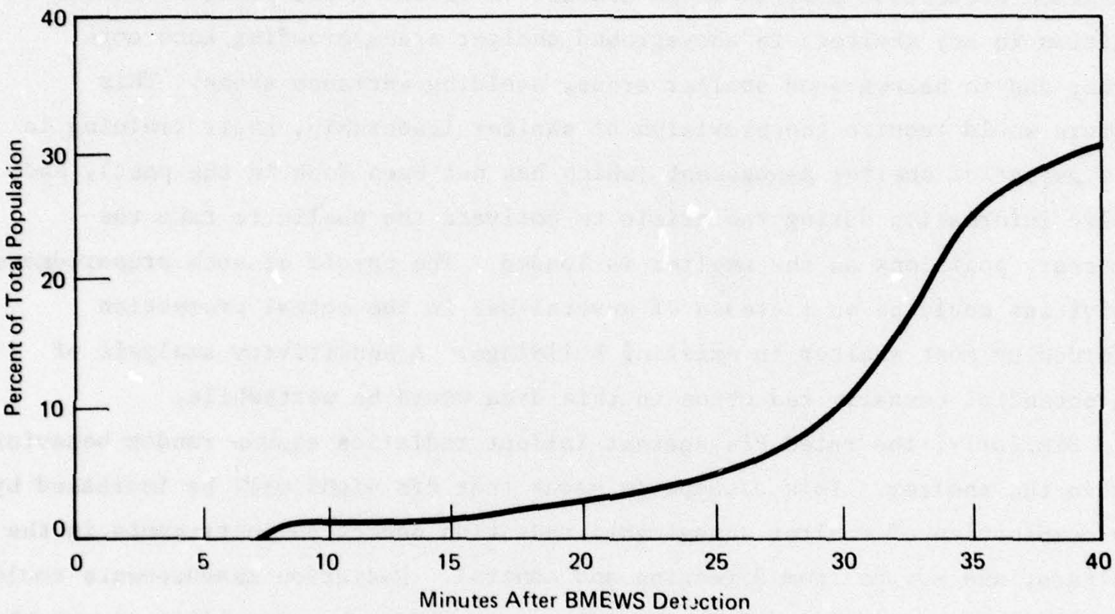

Figure 17 FRACTION OF POPULATION EXPERIENCING AT LEAST 2 PSI BLAST OVERPRESURE

Maximum Protective Posture

We evaluated blast fatalities and injuries from direct effects by use of the MLOP and MCOP ratings provided by DCPA. These are understood to be overall averages for the various building types that make up each category. Presumably, a "maximum protective posture" event prior to detonation could result in substantially increased blast protection compared to the rated protection. As outlined in Chapter 2 of the DCPA Attack Environment Manual, a maximum protective posture would consist of assuming the prone or seated position in any shelter; in aboveground shelter areas, crowding into core areas; and in belowground shelter areas, avoiding entrance areas. This posture would require the provision of shelter leadership, their training in this aspect of shelter management (which has not been done in the past), and public information during the crisis to motivate the public to take the necessary positions as the shelter is loaded. The payoff of such preparedness activities could be an increase of several psi in the actual protection afforded by most shelter in existing buildings. A sensitivity analysis of the potential casualty reduction in this area would be worthwhile.

Similarly, the rated PFs against fallout radiation assume random behavior within the shelter. This assumption means that PFs might well be increased by the combination of shelter management, radiation detection instruments in the shelters, and advice from direction and control. Radiation measurements could indicate the safest parts of the building area under the prevailing circumstances. Calculations have been made[11] of the increased protection afforded by crowding together and other behavioral measures. Additional work is needed to quantify this aspect for use in effectiveness analyses.

Vulnerability in the Open

DCPA does not have established values of MLOP and MCOP for people in the streets at the time of attack. Many of the authoritative documents consulted, such as the DNA Effects Manual EM-1, the DIA Vulnerability Handbook, and the Combat Developments Command Personnel Risk and Casualty Criteria, vary considerably in predicted effects and do not directly consider people in urban streets. Some unclassified data from EM-1 for a 1 MT detonation are indirect indications of human vulnerability:

2nd degree burn (3 sec. evasion)	8½ miles from GZ
Extent of 2 psi	5 miles
50% damage to multistory wallbearing building	2-3/4 miles
50% damage to wood-frame building	3.4 miles

If the stated damage to buildings is assumed to correspond with 50 percent fatalities from being struck by building debris, then the extent of 2 psi is a reasonable average between the casualty mechanism of blast and that of thermal phenomena. This average would assume that half of those in the streets would be shielded from thermal radiation.

Davis et al[12] offer the estimate of 2 psi MLOP and 1 psi MCOP for people partially shielded from thermal radiation. We have adopted these values for this study.

The Fire Threat

The number of shelterees killed and injured by fire growth and spread following nuclear detonations has not been clearly determined. Most of the burns suffered at Hiroshima were apparently due to thermal radiation impinging on the many people in the streets and at windows. For many years, the blast casualty curves based on Hiroshima included by implication such fire deaths as occurred. To attribute a substantial portion of the fatalities and injuries to fire growth and spread would have implied a much lower vulnerability to blast and initial radiation than was believed to be the case. On the other hand, virtually all wooden structures in an area of several square miles were eventually burned, forcing survivors into open areas. If fallout had been present, more fatalities and injuries might have been caused by this hazard.

Lommasson and Keller[13] have estimated the fire fatalities at Hiroshima to be about 3 percent of the population at risk. If this factor had been applied to the survivors of direct effects in this study, it would have modified our results only slightly. In DAL-69, the last OCD study, persons in burning buildings who survived direct effects and would have survived fallout radiation if permitted to remain there were estimated to make up 6 to 8 percent of the survivors. Fire casualties were not assessed directly. Also, fire spread was not considered.

Application of a fire-spread model[14] suggests that perhaps half of the shelters in existing buildings might become untenable in the absence of fire countermeasures. Fire-spread models are limited in that they are based on data and theory for uncrushed structures. Moreover, the results cited assume

that initial ignitions are unaffected by the blast wave. The 1977 edition of The Effects of Nuclear Weapons states:

> "Since most of the thermal radiation reaches a target before the blast wave, the subsequent arrival of the latter may affect the development of fires initiated by the thermal radiation. In particular, there is a possibility that such fires may be extinguished by the blast wind. Studies of the effects in Japan and at various nuclear and high-explosive tests have given contradictory results and they leave the matter unresolved. Laboratory experiments that simulate blast loading of urban interiors show that the blast wave typically does extinguish flames but often leaves the material smoldering so that active flaming is revived at a later time. It is not certain, however, to what extent this behavior would apply to actual urban targets subjected to a nuclear explosion. Although some fires may be extinguished by the blast, many others will undoubtedly persist."

In view of the contradictory and uncertain elements in the current state of knowledge, we chose not to assess any fire fatalities directly and to assume the upper bound on the fraction forced out of shelters, somewhat in compensation. We assumed that half of the shelters were abandoned, with the exception of the Category A shelters -- subways, mines, caves, and tunnels.

The time at which shelters would become untenable because of the fire threat must also be quantified, either as an average time after detonation or as a time distribution. The available data suggest that the time can vary from about an hour after detonation for a small building initially ignited to several days later for buildings eventually ignited by fire spread.[14] For this demonstration, we chose one day after detonation as a representative time.

There are a number of possibilities for improving this aspect of casualty assessment. In the machine computation, the fire-spread or conflagration potential of each risk-area grid square might be assessed and used to estimate the fraction of untenable shelters and the likely time of abandonment. One potential measure is population density, which can be computed with the data already associated with each grid square. It may also be possible to tag each grid square as being "downtown," "central city," or "urban fringe" in its predominant characteristic. Building density is probably a difficult parameter to establish but it may be possible to identify grid squares as largely residential, business, or industrial in construction characteristics. The shelter survey may be a useful clue in this regard. Sensitivity analysis

using data on a few local areas would be useful in determining whether it is worthwhile to program a more complex definition of fire risk.

In addition, the whole subject of fire phenomena deserves priority research, especially the blast-fire interaction problem, as the resolution of these uncertainties has a critical effect not only on the matter of casualty assessment but also on the payoff of fire countermeasures both in the crisis period and during the attack. Meanwhile, casualty assessments over a reasonable range of assumptions as to direct fire casualties and premature abandonment of shelters can give guidance on the critical parameters and performance values.

Shelter Stocks

Among the various items of shelter stocks, other than ventilation devices and radiation detection instruments, we have considered only the availability of drinking water as a matter affecting the vulnerability of the population. The availability of food, sanitation, and medical supplies probably has some effect on the ability and willingness of people to remain in public shelter but we have found no basis for quantifying this effect. The availability of these items also would influence the willingness of people to go to public shelter but we chose not to adjust the fraction of stay-puts on this basis. Further work is needed to quantify these factors.

With regard to the lack of drinking water, two issues must be addressed: could water be readily obtained after attack, and if not, when would the shelters have to be abandoned? On the first issue, our judgment was in the negative. For one thing, premature abandonment of shelter would produce significant casualties in the areas of heavy fallout. For another, the overriding problem in obtaining and storing drinking water is the container problem. Assuming that a convenient water source could be found nearby, only a few shelterees would need to make many trips with the sort of containers that might be available and readily carried. Large containers could not be handled. While there would undoubtedly be instances of successful bringing of water to shelters, it is more likely that in most cases, thirst would drive the shelterees to seek water outside. Again, if the source of water were nearby, the shelters might be occupied part of the time (partial use of shelters). For demonstration purposes, we chose an "all or none" condition --

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the shelters would either have water or have no water. Thus, undamaged residences were assumed to have an adequate supply of water. The criterion used was that the survivors had experienced less than 4 psi. In the non-risk area, we also assumed that half of the unstocked public shelters would have water because of gravity water supply or indigenous tanks. In all other cases, it was assumed that the shelter would have to be abandoned.

On the second issue (with no water, when would the shelters have to be abandoned?), it is known that lack of drinking water can cause death in a matter of hours in a hot, dry climate and in a week to ten days in a cool, moist climate. In general, the population in unstocked shelters could remain longer in the winter than in the summer. Wright et al[15] have reviewed the experimental evidence on this matter and reached these conclusions:

> "One of the essential elements in surviving an extended shelter stay is the provision of clean, safe water. While people can survive for extended periods (two or more weeks) without food, just a few days (two or three) without water can produce either serious physiological consequences or death. Water is especially critical to life support in a hot environment."

In DAL-69, OCD assumed that people in unstocked shelters could stay for two days, followed by partial use of the shelter. In this demonstration, we also assumed a two-day stay and included the partial use of shelter in our generalized term, "Remedial Movement," as discussed below in the paragraphs on Post-Emergence Countermeasures.

This factor in casualty assessment deserves further analysis. The significance of a lack of drinking water is closely related to the shelter environment and hence, the availability of adequate ventilation. Both factors have not only a seasonal variation but also a climatological one that depends on the geographic location of the particular grid square. It may be possible to associate a variable time of abandonment with the various parts of the country. Additionally, the matter of supply and resupply of water after an attack, either by shelterees or by the CD organization, should be examined more carefully.

<u>Ventilation Adequacy</u>

The most urgent need for ventilation in shelters is to remove the heat and moisture given off by the shelterees, especially when the shelters are occupied to near their capacity. Families or small groups in residential

basements do not have this problem. Experimental data suggest that natural ventilation through windows in aboveground shelter areas will be sufficient to control temperature and humidity within safe levels. Thus, the question of ventilation adequacy pertains mainly to belowground shelters housing large groups of people. These shelters are also those usually offering the best fallout protection.

We used the information embodied in Figure 13 as the basis for assessing casualties in belowground shelters without ventilation kits. Since the information was drawn from an internal OCD document of the mid-1960s, its current validity should be reviewed. Moreover, we used the single value of 0.4 as a national average of the reliability of natural ventilation. In future machine computations, each grid square should be given a reliability factor appropriate to its geographic location.

To quantify the time at which such shelters would become untenable, we reviewed the large number of simulated occupancy tests that were accomplished for OCD by Florida State University, General American Research Division, Pennsylvania State University, and Research Triangle Institute. We found that the question of when shelterees were likely to abandon the inadequately ventilated shelter had not been addressed. Therefore, we made a cursory analysis of those records that gave a time history of the buildup of heat and humidity (jointly measured by effective temperature -- ET).

We noted that at marginal ventilation rates there was a pronounced diurnal variation in the shelter ET; it was lower at night when the ventilation air was cool than in the daytime. We found a population survival curve[16] that related the duration of high ETs to fatalities. These curves are shown in Figure 18. If an ET of 82 degrees is taken as the criterion, it can be seen that a period of 10 hours or more is required before heat prostration in the more vulnerable segments of the shelter population would signal abandonment of the shelter. A survey of experimental results indicated that the necessary duration of 82 degrees ET occurred at about two to three days after shelter occupancy, on the average.

As noted before, ventilation adequacy is intimately associated with availability of drinking water. Accordingly, we chose three days as the average time of shelter emergence for ventilation inadequacy at natural rates of ventilation. That is, if both water and ventilation were inadequate, the two-day emergence would control; only if water supplies were adequate would the three-day emergence occur.

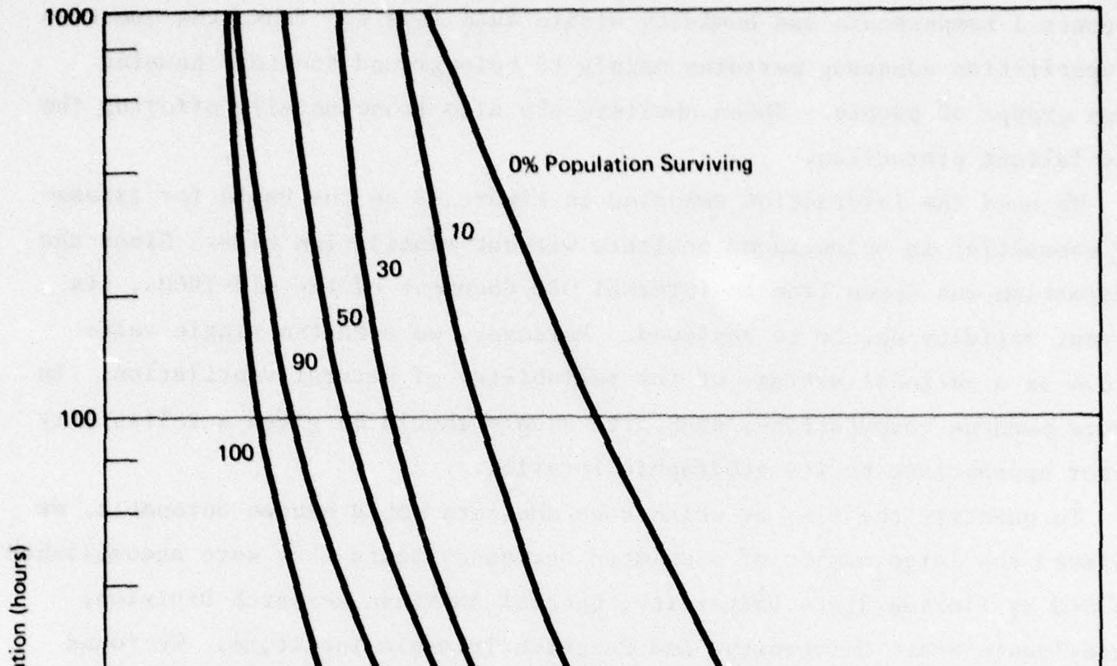

Figure 18 APPROXIMATE POPULATION SURVIVAL CURVES

Since shelter stocking costs, including ventilation, are often a substantial part of the preparedness system costs for many candidate CD programs, it is important to explore the relationship of water supplies and ventilation and to validate the conclusions reached in this brief evaluation.

Normal Shelter Staytimes

In this study, we have assumed that unless some imminent threat to life develops, people will remain in fallout shelters until they are advised by their government officials otherwise. We have taken the maximum period to be two weeks, conditioned by the possibility that additional protective measures, such as remedial movement, may be needed thereafter. Of course, in areas of low fallout risk, emergence can occur much earlier. This earlier time can be known only through analysis of radiation measurements and communication of the results in a credible way. Hence, our evaluation of the "No Civil Defense" case in Section III is probably too optimistic. Whenever radiological information is lacking or communications are uncertain, the behavior of the sheltered population should be regarded as insensitive to the threat and subject to other pressures. Nonetheless, attitude surveys indicate that the majority of those who profess to know believe that they will need to stay in shelter for two weeks. Sensitivity analyses should be made to assess the importance of reinforcing this belief in terms of casualty reduction.

Post-Emergence Countermeasures

The demonstration results in Section III show that for a large-scale surface-burst attack, several million additional radiation deaths and injuries can occur in the U.S. population if shelter emergence occurs at two weeks after attack. These casualties can be avoided by the use of radiological countermeasures that have normally been regarded as part of the process of postattack recovery: remedial movement, decontamination, rotation and shifts, and partial or continued use of shelters. These measures, individually or in combination, can achieve an order-of-magnitude reduction of the hazard. We generalized this group of countermeasures -- and their primary support measures: radiological monitoring, communications, and direction and control -- under the term, remedial movement, partly because we believe that it would prove to be the most widely used measure following an actual attack.

In our example calculations, we used a PF of 5 for the no-countermeasure condition after shelter emergence. This PF represents what we might term,

"cautious living." That is, everyone knows that the environment is polluted and tries to limit his exposure to the extent possible. A person perpetually in an open field rates a PF of about 1.5. If he is part-time in the open and part-time in a vehicle or light building, he rates a PF of about 3. This might be termed, "incautious living." We used a PF of 3 for people during the assumed four-hour period of remedial moving. If most people spend most of their time indoors and sleep in a basement or other protected spot, they rate a PF of 5, or cautious living.

Rather than actually move people postattack, it was assumed that an order-of-magnitude reduction of hazard could be represented by a PF of 50. Thus, the remedial movement case consisted of a specified stay in a shelter having a given rated PF, followed by four hours at a PF of 3, and then a final PF of 50. It is clear that this calculation could also represent decontamination or partial shelter occupancy as well, although specific calculations for these measures could be made if warranted.

The application of these measures in the demonstration results was made by considering the surviving extent and quality of the functions and controls needed to carry them out. This evaluation was not made in detail and was to an extent judgmental. We estimated that the initial capabilities in the risk area were considerably greater than those in the nonrisk area, except when crisis relocation had been carried out, but were degraded by the damaging effects of the detonations. We noted that detonations tended to cluster in urban areas so that survivors were generally in the peripheral regions of attack where movement was naturally out of the damaged area. At least half of the survivors (those going upwind and crosswind) would be moving into areas of lower fallout risk. Having made a judgment of probability of success, we applied the judgment to both risk and nonrisk areas. A more detailed analysis might have resulted in a separate probability in each area.

One obvious oversimplification was our assumption that the probability of successful remedial movement was independent of the time at which the movement occurred. It is more plausible that the probability of success increases at later times. For example, remedial movement at D+1 (fire threat) is obviously complicated by the fact that the radiological situation is still changing (fallout is still occurring) and fragmentary information has to be evaluated before any orderly attempt at remedial movement can be mounted. On

the other hand, remedial movement at D+14 could count on a stable radiological situation, time for evaluation and planning, and time for communication and other preparations. At this time, we are not in a position to defend specific estimates of how the probability of success might vary. The time variation is an obvious area for improvement in the quality of the assessment.

Machine Computations

In the foregoing discussion, numerous possibilities for improving the quantification of the key factors in the casualty assessment have been noted for application in a machine calculation at the grid-square level of detail. In this study, the machine calculations were intended to be identical with the hand calculation assumptions except for the use of casualty functions in lieu of a cookie-cutter solution and except for the assessment of vulnerability at the grid-square level of detail. A description of the computer program will be found in Appendix B. In the course of its development, simplifications were made in the existing DCPA routine that permitted a reduction in machine time despite the more complex analysis.

The comparison of the hand calculation with the computer result indicates that the hand calculation should be adequate for sensitivity analyses, comparisons of relative worth of measures, and exploration of improved assessments prior to a decision to revise or expand the machine assessment routine. The machine computations outlined in Appendix B thus represent a first step in implementing the methodology described in this report. It is likely that many of the cited improvements can be accomplished "off-line" to provide factor values for use in the machine calculations. On the whole, it appears that an assessment procedure that reflects the defense scenario consistent with the state of knowledge is well within the bounds of DCPA computational capacity.

V. SUMMARY AND RECOMMENDATIONS

Summary of the Method

The method developed in this study and demonstrated in the previous sections of the report incorporates the following approach:

(A) A distinction is made between the operating system, which functions during the crisis period, transattack period, and post-attack period, and the preparedness system, which functions during peacetime to provide capabilities for the operating system. Operating functions are performed by resources -- personnel, facilities, equipment, and supplies -- either extant in the society or purchased by the preparedness system. Civil defense costs are those incurred by the preparedness system. These costs are reflected in the addition of new resources or in the maintenance of readiness to use existing or previously acquired resources. An analytical procedure is provided for tracing the path from operating resources to budget categories or vice versa. This procedure is necessary to relate cost increments to changes in operating performance.

(B) A change in operating resources must be reflected in a change in population vulnerability (MLOP, PF, etc.) in order to measure performance in terms of casualty reduction. This requirement has been met in past cost-effectiveness studies by "excursions" from a base program to calculate the cost per added survivor of alternative warning capabilities, shelter stocking options, and the like. The method proposed here incorporates these elements routinely into a "defense scenario," which is the basis for calculating casualties under exemplar attacks. Although the demonstration of the method is limited to consideration of the performance of a set of civil defense programs under one assumed attack, the defense scenario approach is equally useful in exploring the effect of changes in only one countermeasure or countermeasure set and in exploring the effectiveness of a program element or program under a range of attack scenarios. For these purposes, functions other than those under consideration are held constant. The joint performance and interrelationship among several functions can be investigated in a similar way. Finally, the potential effectiveness of countermeasures and uncertainties in associated performance estimates can be evaluated by parametric analysis, allowing assumptions to vary over an appropriate range.

(C) The methodology as currently conceived permits, and indeed encourages, the analysis of weapons effects, population vulnerability, countermeasures, and behavioral issues outside of the casualty assessment routine itself. While it would be possible to model these matters on the computer to a great extent, the calculations

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would greatly extend computing time. Moreover, changes in technical understanding would most likely require reprogramming of much of the auxiliary computations. Hence, the method assumes for the most part that the results of off-line analysis will be used as inputs to the casualty assessment procedure. That is, the result of a detailed comparison between warning and tactical movement dynamics and an assumed attack lay-down would be reflected in an estimate of the fraction of the risk population in the open at detonation. Similarly, external analyses would define the fraction of stay-puts, the amount and timing of shelter abandonment because of fire spread, and the like. In the event that it becomes practical to associate some of these factors with grid-square characteristics, such as population density, shelter characteristics, census designations, climate, etc., external analyses still would be used to determine the appropriate factors and look-up tables that would be used in the machine computation.

(D) Experience with the machine computations outlined in Appendix B suggests that the proposed casualty assessment procedure is well within the capacity of the DCPA computer facility. Modifications made during this study actually reduced the running time of the casualty assessment program, even though the existing program was expanded to include calculations concerning effective protection factors. Of course, the program in Appendix B has been simplified to match the hand calculations of Section III of this report. Nonetheless, when more detailed subroutines are added, such as calculation of ventilation adequacy as a function of geographic location, it is unlikely that the more complex program will require in excess of two hours on the central processor for a national run.

(E) It has also been demonstrated that a hand calculation using two matrices generated by the attack environment portion of the computer program can be used for casualty assessment with acceptable accuracy, especially if a few machine computations are available to permit normalization of the results. This characteristic of the method is a powerful tool for analysis. It will permit many aspects of the civil defense operating system to be evaluated without expenditure of computer time. Sensitivity analyses of assumptions and calculations of the marginal effectiveness of various measures can be accomplished at the desk. Such calculations, displayed in the form of a defense scenario, are subject to objective review by technical experts and decision-makers in a way that cannot be provided by a machine computation. Moreover, the analyst, whether in-house or under contract, is in direct control of the calculation without the intervention of a programmer. Finally, improvements in the methodology can be evaluated for significance and worth before investment in programming effort.

Summary of Demonstration Results

The methodology has been applied to a range of civil defense postures and candidate programs. As noted in the Introduction, most of these calculations were made to support DoD program review activities. Hence, the results are incorporated in classified documents. Only a few results, suitably adapted, have been included in this report as a means of demonstrating the methodology. They are:

Posture	Fatalities	Injuries	Uninjured Survivors
No CD	80%	7%	13%
Current CD	76%	8%	16%
Program A	69%	10%	21%
Program B (In-Place Option)	62%	11%	27%
Program B (Relocation Option)	19%	13%	68%

These results were based on the attack environment posited for a large-scale attack that might be feasible -- though possibly unlikely -- in the mid-1980s. It is shown that the range of population fatalities can vary from 20 percent to 80 percent depending on the effectiveness of civil defense measures. The stated performance of civil defense programs is not an idealized performance value but rather an estimate of effectiveness that attempts to incorporate not only the likely performance of the civil defense capabilities bought by the budgeted activities but also the anticipated behavior of the public. Thus, while the individual estimates and judgments are subject to critical review and challenge, the methodology is of the type that clearly identifies the inherent vulnerabilities of the population, the practical limitations on countermeasures, and the responses of people to threats to their survival. It is a fit tool for policy determinations on both strategic and tactical aspects of population defense.

Limitations of the Method

Section IV discusses in a summary fashion the current limitations on the validity and accuracy of effectiveness calculations using the proposed methodology. A pervasive problem is the limited evidence

available to form the basis for performance estimates and behavioral assumptions. Time has not permitted an exhaustive review of the pertinent literature during this study. Nonetheless, it is clear that the application of the methodology presses hard on our state of knowledge regarding weapon effects, countermeasure performance, emergency operations, direction and control, communications, training effectiveness, and human behavior. On the other hand, the method will permit the framing of important questions in specific terms for use in analysis of available data and the implementation of further research. In addition, sensitivity analysis over the range of uncertainty in current estimates of particular parameters can indicate priorities and form the basis for confidence statements on the effectiveness of both programs and program elements.

A potential limitation of the methodology may be the need to use average or effective values for complex distributions. Many such approximations are evident in the demonstrations of Section III: effective fallout arrival times, "all or none" abandonment of shelters, average times of shelter leaving, and the like. A special case has been the use of DCPA shelter categories that group a wide variety of existing structures of a general type for purposes of assigning protective characteristics based on the analysis of a small sample. To model fully the variability inherent in all of these areas is probably beyond the realm of computational capacity as well as the technical state of the art. Again, however, sensitivity analysis requiring a relatively few special machine runs can be expected to identify where approximations can be used validly and where they should not be used.

Knowledge of human behavior under crisis and disaster conditions will limit to some degree the confidence that can be placed in the results of applying this methodology in determining the cost-effectiveness of civil defense programs. This issue is most likely to affect the interpretation of predictions of absolute performance rather than the relative performance of alternative programs or investments in capabilities.

Some current difficulties in allocating Federal budget projections to operating system functions and controls are described in Section II. The essence of the difficulty is that budget descriptions and justifications have not been prepared with this need in mind. It seems likely, however,

that continued consultation between those concerned with program planning and evaluation and those concerned with cost budgeting and documentation will ease this problem. Moreover, if cost-effectiveness becomes an important element of budget justification, adaptation to the analytical requirements will undoubtedly occur.

Recommendations

On the basis of work accomplished and reported here, the following recommendations are offered:

(1) The assessment concepts developed in this work should be adopted by DCPA as the basis for agency cost-effectiveness analyses and contributions to DoD and interagency studies.

(2) Appropriate staff members should be trained in the use of the methodology.

(3) Further analytical work should be undertaken to improve the technical basis for quantification of operating system element performance. This work should be done initially as an integral part of a continuing effort to improve the methodology and to mitigate the limitations on interpretation of results. Specific questions and problem areas identified in the analysis should be used as a basis for research programming.

(4) Sensitivity analyses of both assumptions and performance estimates should be accomplished to provide guidance on the implications of current uncertainties and to place bounds on the confidence in the results of applying the method. These analyses can employ both hand calculations and machine runs, depending on the requirements of the analysis.

(5) Additional analysis is recommended to expand the casualty assessment procedure to include all system and program elements that are identified as contributing in any way to casualty reduction. A number of these potential contributors, including training of shelter managers, stocking of shelter instruments, and fire prevention and control activities, are discussed in Section IV.

(6) More analysis is also needed to permit the separation of the joint performance of components of a countermeasure set into performance measures for the individual components of a set. Currently, the elements can be separated only on an arbitrary basis. An essential element of this work must be to assess the value of redundancy in improving the reliability of functional performance where, as is often the case, alternative resources and use of resources can be applied to a given function. A full definition of the contribution of many support measures cannot be arrived at without this additional study.

(7) In addition to the foregoing, it is desirable to explore the use of other measures of effectiveness beyond that of casualty reduction. Many civil defense operating functions and program elements are likely to be justified in terms of these broader measures. Among the measures of effectiveness that should be investigated are the avoidance of debilitating late effects of radiation exposure, early return of the injured and sick to the work force, continuity of government and elected authority, and economic and social recovery from the effects of attack.

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Appendix A

ANALYSIS OF THE FY 1978 DCPA BUDGET

Appendix A

ANALYSIS OF THE FY 1978 DCPA BUDGET

Introduction

This analysis of the DCPA budget was made to obtain realistic cost figures for a demonstration of the normal practice. Normally, when systems analysis provides information for program decisions, operating system requirements for personnel, facilities, equipment, and supplies are identified with the appropriate countermeasures, costs are estimated in terms of the preparedness system functions and controls, and then, if necessary, the costs are transformed into the budget format. In the analysis, the procedure was reversed: the summary costs shown in the budget were identified with the appropriate preparedness functions and controls, and then with the operating system countermeasures for which they were to be expended.

To simplify the tabulation of the cost estimates, codings were used for the operating system countermeasures and the preparedness system functions and controls. The codes are shown in Tables A-1 and A-2. The codes are read from left to right. For example, the operating system countermeasure "Acquiring Data - Environment" is: 0. (Operating System), C. (Control), 3. (Informing), 1. (Data), 1. (Acquiring), 3. (Environment); i.e., 0.C.3.1.1.3.. The analysis was carried only to the second digit.

In the analysis, the language of the Justification* was compared to that of the definitions of the functions and controls of both systems, and conclusions were drawn as to the allocation of the estimates to the system elements. Sub-object codes were added from the budget execution plan.

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*Justification of Estimates - FY 1978, DCPA.

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O. Operations System	F. Functions	1. Sheltering	1. Shielding		
			2. Controlling Environment		
			3. Providing Utilities		
			4. Medical Care		
			5. Maintaining Health		
			6. Fire Fighting		
			7. Maintaining Law & Order		
			8. Feeding		
			9. Decontaminating		
		2. Warning	1. Alerting		
			2. Informing		
		3. Moving	1. Strategic		
			2. Tactical		
			3. Remedial		
		4. Rescuing			
		5. Maintaining Health	1. Sanitation		
			2. Controlling Disease		
			3. Controlling Vectors		
		6. Fire Fighting	1. Preventing	1. Screening	
				2. Inhibiting	
			2. Suppressing		
		7. Maintaining Law & Order	1. Suppressing Crime		
			2. Maintaining Order		
		8. Protecting Livestock			
		9. Protecting Industry	1. Hardening		
			2. Emergency Shut Down		
		10. Medical Care	1. Collecting		
			2. Treating		
		11. Feeding	1. Food		
			2. Water		
		12. Housing			
		13. Restoring Facilities	1. Clearing Debris		
			2. Repairing & Replacing		
		14. Decontaminating	1. Structures		
			2. Terrain		
		15. Welfare Services			
	C. Controls	1. Organizing	1. Assigning Authority		
			2. Staffing		
			3. Supplying Resources	1. Support	
				2. Supplies	
				3. Transport	
				4. Control	
		2. Planning	1. Analyzing Problems		
			2. Synthesizing Solutions		
		3. Informing	1. Data	1. Acquiring	1. People
					2. Resources
					3. Environment
				2. Processing	
				3. Storing and Retrieving	
			2. Communicating		
		4. Deciding	1. Evaluating Alternatives		
			2. Selecting Actions		
		5. Commanding	1. Promulgating Decisions		
			2. Reviewing Results		

Table A-1
OPERATING SYSTEM COUNTERMEASURE CODE

P. Preparedness System	F. Functions	1. System	1. Designing	
			2. Testing	
		2. Program Planning		
		3. Facilities	1. Designing	
			2. Surveying	
			3. Marking	
			4. Improving	
			5. Constructing & Maintaining	
			6. Testing	
		4. Equipment	1. Designing	
			2. Procuring	
			3. Stockpiling	
			4. Distributing	
			5. Installing	
			6. Testing	
		5. Supplies	1. Designing	
			2. Procuring	
			3. Stockpiling	
			4. Distributing & Maintaining	
			5. Testing	
		6. Operations	1. Designing & Planning	
			2. Testing	
		7. Organizing	1. Authority	1. Assigning
				2. Channeling
			2. Staff	1. Recruiting
				2. Training
				3. Assigning
			3. Procedures	1. Designing
				2. Testing
		8. Informing the Public		
	C. Controls	1. Organizing	1. Assigning Authority	
			2. Staffing	
			3. Providing Facilities	
			4. Providing Equipment & Supplies	
			5. Providing Operating Doctrine	
		2. Planning	1. Analyzing Problems	
			2. Synthesizing Solutions	
		3. Informing	1. Data	1. Acquiring
				2. Processing
				Storing & Retrieving
			2. Communicating	
			3. Research	
		4. Deciding	1. Evaluating Alternatives	
			2. Selecting Actions	
		5. Commanding	1. Promulgating Decisions	
			2. Reviewing Results	

Table A-2
PREPAREDNESS SYSTEM FUNCTION AND CONTROL CODE

Coding of Estimates

The following tabulation is in the general form of the DCPA Justification of Estimates - FY 1978 supplemented where appropriate by information from the FY 1978 Tentative Budget Execution Plan. Dollar amounts are from the execution plan in thousands of dollars.

Sub-Object Code/BP		Estimate	Operating System	Preparedness System
OPERATION AND MAINTENANCE				
Warning and Detection				
	Warning and Communications Systems			
151-11	National Warning System	$2,610	O.F.2	P.F.3.2
152-11	Washington Warning System	571	O.F.2	P.F.3.2
124-11	CD Nat. Teletype System	979	O.C.3.2	P.F.3.5
126-11	CD Nat. Voice System	372	O.C.3.2	P.F.3.5
125-11	CD Nat. Radio System	1,006	O.C.3.2	P.F.3.5
127-11	Other Communications Service	945	O.C.3.2	P.F.3.5
	Technical and Admin. Support			
221-87		79	O.C.3.2.	P.F.3.5
321-87		350		
320-11	Planning Support	555	O.C.3.2	P.F.6.1
	Radiological Defense			
142-14	Logistical Support	220	O.C.3.1	P.F.4.5
141-13	Equipment Engineering	168	O.C.3.1	P.F.4.1
143-14	Fallout Forecasting	9	O.C.3.1	P.C.3.1
242-14	Main. & Calib. of RADEF Equip.	2,310	O.C.3.1	P.F.4.5
241-13	RADEF Equipment	132	O.C.3.1	P.F.5.2

Emergency Operations

	Training and Education			
	Management			
219-23		$ 7	O.C.(all)	P.F.7.2
319-23		1,026		
	Direction and Control			
229-23		40	O.C.3.2	P.F.7.2
329-23		456		
	RADEF			
249-14		192	O.C.3.1	P.F.7.2
349-14		960		
312-23	Student Expense	40	O.C.(all)	P.F.7.2
369-23	Civil Protection	169	O.F.3.1	P.F.7.2
	Emergency Information			
172-17	Information on CD Programs	301	O.F.(all)	P.F.8
368-27	Liaison Services	16	O.F.(all)	P.F.8
363-27	AE Technical Information	168	O.F.1	P.F.8
471-27	Information on CD Programs	198	O.F.(all)	P.F.8
	Systems Development			
181-24	Management System	26	O.C.(all)	P.F.1.1
186-24	Relocation Planning	100	O.F.3.1	P.F.1.1
184-13	Radiological Defense Planning	26	O.C.3.1	P.F.1.1

	Broadcast Station Protection			
171-21	Maintenance of Shelters	$ 6	O.C.3.2	P.F.3.5
	Maintenance and New Equipment	400	O.C.3.2	P.F.4.5
	Red Cross Advisory Services			
367-29	Assistance and Guidance	194	O.F.(all)	P.F.6.1

Financial Aid to States

For this demonstration, personnel, travel, and communications costs have been proportioned as assumed for the DCPA management budget. In the making of a working estimate, the details of the several items would be available.

	State and Local Management			
214-33	Personnel and Travel			
314-33				
314-33	Program Planning	$ 4,277	O.(all)	P.F.2
	Training	1,210	O.(all)	P.F.7.2
	Informing the Public	2,646	O.(all)	P.F.8
	Administration	4,678	*	P.C.1
	Planning	523	*	P.C.2
	Informing	3,528	*	P.C.3
	Commanding	11,172	*	P.C.5
	Admin. and Housekeeping	2,820	*	P.C.1
	Communications	656	*	P.C.3.2

* These are indirect costs.

State and Local Maintenance and Service

Direction and Control

226-31	Maintenance and Service	$290	O.C.3.2	P.F.3.5
326-31	Maintenance and Service	375		
	Warning			
256-31	Maintenance and Service	176	O.F.2	P.F.3.5
356-31	Maintenance and Service	875		

Management

Personnel and travel costs were distributed to preparedness system functions and controls in proportion to the numbers of people in the several divisions (including Regions, Staff College, etc.). In a working estimate, these details would be available.

114-41	Personal Services	$15,893		
115-42	Travel	730		
	Program Planning	2,528	O.(all)	P.F.2
	Training	715	O.(all)	P.F.7.2
	Informing the Public	1,564	O.(all)	P.F.8
	Administration	2,818	*	P.C.1
	Planning	309	*	P.C.2
	Informing	2,085	*	P.C.3
	Managing	6,614	*	P.C.5
117-43	Admin and Housekeeping	4,900	*	P.C.1
116-43	Telephone Services	670	*	P.C.3.2
118-11	Communications Services	974		

* These are indirect costs.

RESEARCH, SHELTER SURVEY AND MARKING

Shelters				
	Shelter Survey			
362-81	National Shelter Survey	$1,898	O.F.1	P.F.3.2
362-87	Engineering Support Services	2,710	O.F.1	P.F.3.1
	Nuclear Civil Protection Planning			
261-87	Crisis Relocation Planning	4,504	O.F.3.1	P.F.6.1
361-87	Shelter Marking			
365-82	Decision Information Distribution System	324	O.F.1	P.F.3.3
153-85	Maintenance of Facilities	122	O.C.3.2	P.F.3.5
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225-32	Supporting Materials	305	O.C.3.2	P.F.4.5
325-72	Supporting Materials	1,224		
	Warning Systems			
255-72	Supporting Materials	229	O.F.2	P.F.3.5
355-72	Supporting Materials	1,842		
Research and Development				
191-90	Nuclear Civil Protection	2,575	O.(all)	P.C.3.3
	Physical Protection	1,825	O.F.1	P.C.3.3
	Emergency Operations	845	O.F.(all)	P.C.3.3
	Systems Analysis	1,355	O.(all)	P.C.3.3
	Training, Education, and Organization	300	O.C.1	P.C.3.3

Appendix B

CASUALTY ASSESSMENT PROGRAM DESCRIPTION

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CASUALTY ASSESSMENT PROGRAM DESCRIPTION

Introduction

A methodology has been developed to more realistically estimate civil defense system effectiveness in terms of program elements, human behavior, and their effects on performance. The methodology has been incorporated into the computerized damage assessment program used by DCPA, and two test cases have been run demonstrating that the methodology works and that the overall computer results are quite close to the results previously produced by hand and discussed in the text. The following paragraphs outline the calculations performed by this computerized methodology and describe the inputs required.

Outline of Calculations

The calculations are performed for each unit area in turn, and the results are summed to provide national totals. The main program provides the following inputs describing the unit area to the subroutine implementing the methodology discussed here. These imputs are:

$$K = \begin{cases} 1, & \text{if a risk area} \\ 2, & \text{if a non-risk area} \end{cases}$$

DOSE = maximum ERD (equivalent residual dose) in the unit area

PSI = peak overpressure in the unit area

P(I) = population in shelter class I (I = 2,.., 9).

There are 10 shelter classes considered, and these are described below:

Class	Description
1	Stay-puts (i.e., people who are assigned to public shelter but do not go)
2	Home basements
3	Subways, mines, caves
4	Strong basements
5	Strong building areas
6	Weak building areas
7, 8, 9	Expedient, upgraded, or constructed shelter
10	Exposed (i.e., people caught in the open by direct weapon effects on their way to public shelter)

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In addition to the inputs provided for each unit area by the main program, the following inputs are required:

PF (I, K) = rated protection factor for shelter class I and area type K (I = 1,..., 9 and K = 1, 2)

TA (K) = fallout arrival time in area type K (K = 1 denotes risk area and K = 2 denotes non-risk area)

TF = time after the attack when people are forced to leave shelter because of fire

TW = time at which people are forced to leave shelter because of lack of water

TV = time at which people are forced to leave shelter because of ventilation problems

TE = the nominal time for shelter emergence

TM = time required for remedial movement after leaving shelter

PFN = protection factor after leaving shelter in the non-remedial movement case

PFM = protection factor during remedial movement

PFR = protection factor after remedial movement

FS = stay-put fraction

FE = fraction caught in the open enroute to shelter

FF (I, K) = fraction that leave shelter because of fire in shelter class I and area type K (I = 1, ..., 9 and K = 1, 2)

FW (I, K) = fraction that leave shelter because of lack of water in shelter class I and area type K (I = 1, ..., 9 and K = 1, 2)

FV (I, K) = fraction that leave shelter because of ventilation problems in shelter class I and area type K (I = 1, ..., 9 and K = 1, 2)

FR (K) = fraction subject to remedial movement after leaving shelter in area type K (K = 1, 2)

MLOP (I) = mean lethal overpressure for shelter class I (I = 1,.. , 10)

MCOP (I) = mean casualty overpressure for shelter class I (I = 1,.. , 10)

Given the above inputs, the calculation proceeds as follows for each unit area. First, the number of stay-puts, P(1), is calculated by multiplying FS times the total number of people assigned to public shelter. Next, the number of people caught in the open, P(10), is calculated by multiplying FE times the total number of people that actually attempt to reach public shelter. The quantities P(3) through P(9) are then appropriately decreased so that they give the numbers of people assigned to each of the public shelter classes that actually reach shelter before the attack.

Once the values of P(I) (I = 1, .., 10) have been determined, the numbers of people killed and injured by blast in each shelter class can be calculated using the psi value for the unit area, as well as the values of MLOP (I) (I = 1, .., 10) and MCOP (I) (I = 1, .., 10) and then entering the appropriate probability distributions that relate probability of fatality (or casualty) to overpressure, which are implemented as subroutine in the overall damage assessment program. After this procedure is carried out, the blast survivors among those caught in the open are distributed appropriately among the public shelter classes, resulting in a small adjustment to each of the values P(3) through P(9).

In order to correctly calculate fallout deaths and injuries, it is necessary to subdivide each shelter class I into eight sub-classes, reflecting those fractions of people that have to leave because of fire, water, and ventilation problems, as well as the fractions that are (and are not) provided remedial movement after leaving shelter. Let FF, FW, FV, and FR denote the appropriate fractions for fire, water, ventilation, and remedial movement, as defined above. Then the eight sub-classes and the fractions of people in each are as follows:

Sub-class	Definition	Fraction in Sub-class
1	Leave because of fire, no remedial movement	FF(1-FR)
2	Leave because of fire, with remedial movement	FF·FR
3	Leave because of water, no remedial movement	(1-FF)·FW·(1-FR)
4	Leave because of water, with remedial movement	(1-FF)·FW·FR
5	Leave because of ventilation, no remedial movement	(1-FF)·(1-FW)·FV·(1-FR)

6	Leave because of ventilation, with remedial movement	(1-FF)·(1-FW)·FV FR
7	Leave at nominal shelter emergence time, no remedial movement	(1-FF)·(1-FW)·(1-FV)·(1-FR)
8	Leave at nominal shelter emergence time, with remedial movement	(1-FF)·(1-FW)·(1-FV)·FR

The time history of fallout protection differs for each unit area type, each shelter class I, and each of the eight sub-classes. Thus, an effective protection factor, PFE(I, J, K), needs to be calculated for each shelter class I (I = 1, .., 9), sub-class J (J = 1, .., 8), and area type K (K = 1, 2). An effective protection factor is defined as the protection factor resulting in the same maximum ERD that results from the given time history of actual protection factors and fallout arrival times and intensities. The procedure used to calculate effective protection factors is outlined in the following section.

Given the values of F(I, J, K), which are the fractions of people in each sub-class J for shelter class I and area type K, as well as the values for PFE(I, J, K), P(I), and DOSE in the unit area, the numbers of people killed (and injured) by fallout in each shelter class I and sub-class J can be calculated by entering the appropriate probability distributions relating probability of fatality (or casualty) to dose level, which are implemented as subroutines in the overall damage assessment program.

Calculation of Effective Protection Factors

The equivalent residual dose, at time t, resulting from fallout arrival at time t_1 (both t and t_1 are measured in hours from weapon detonation), where both the H+1 hour intensity and the protection factor are taken as unity, is given by

$$\text{ERD}\,(t_1, t) = f \int_{t_1}^{t} x^{-k} dx + (1-f) e^{-\beta t} \int_{t_1}^{t} e^{\beta x} x^{-k} dx,$$

where f = 0.1, k = 1.2, and $\beta = 0.025/24$. The second integral cannot be evaluated in closed-form. However, an accurate numerical approximation technique for evaluating the above expression has been implemented in a fast-running subroutine.

Consider now a situation where protection factors and/or the fallout environment change from time to time. Let

PF_i = protection factor in the time interval from t_i to t_{i+1} $(i = 1, \ldots, n)$

R_i = sum of the H=1 hour intensities for all weapons whose fallout has arrived by time t_i $(i = 1, \ldots, n)$

If D(t) is defined as the total equivalent residual dose at time t, then it is given by the expression

$$D(t) = \frac{R_1}{PF_1} \cdot ERD(t_1,t) + \sum_{i=2}^{j} \left(\frac{R_i}{PF_i} - \frac{R_{i-1}}{PF_{i-1}}\right) ERD(t_i,t)$$

where j satisfies $t_j \leq t < t_{j+1}$. (Note: t_{n+1} is assumed to be infinite.) The value of t that maximizes this expression, t_{max}, is found by numerical search, and the effective protection factor, PFE, is then found by solving

$$PFE = \frac{ERD(t_1,t')}{D(t_{max})},$$

where t' is that time at which the value of ERD (t_1,t) is maximized.

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Center for Planning and Research, Inc., Palo Alto, CA
February 1978 129 pp. Contract No.DCPA01-77-C-0223
Work Unit 4114H

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